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Application of stochastic downscaling techniques to Global Climate Model data for regional climate prediction

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APPLICATION OF STOCHASTIC DOWNSCALING TECHNIQUES TO GLOBAL CLIMATE MODEL DATA FOR REGIONAL CLIMATE PREDICTION

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ABSTRACT

Global warming is the most important issue of the present day that affects the climate drastically. This research was carried out to find out the effects of Global warming on Louisiana in future on a very finer spatial and temporal scale. For this purpose spatial downscaling technique is used, where finer resolution climate information is derived from a coarser resolution Global Climate Model (GCM) output. Empirical/statistical downscaling method is used in which sub grid scale changes are calculated as a function of large scale climate. For this purpose a stochastic weather generator and two Global models are considered. The two global models are CCCma (Canadian Center for Climate Modeling and Analysis) and CSIRO (Australia's Commonwealth Scientific and Industrial Research Organization). The stochastic weather generator used is Climate Generator (CLIGEN). The global monthly means are calculated until the year 2090 from the available daily data of CCCma and CSIRO and the units are converted according to that used in CLIGEN. The monthly means of the parameter files of CLIGEN are replaced with the Global monthly means, and the other statistical parameters such as standard deviation, skewness, etc are changed accordingly and weather is generated using the CLIGEN until the year 2090 for Louisiana. Statistical analysis is performed for the climate generated using the two Global models and comparisons are made between the results of the two models. Also time series plots are drawn for the generated climate of the two models taking one year as a representative year.

CHAPTER 1: INTRODUCTION

The term weather is generally used to denote day to day variations in temperature, rainfall, snowfall, wind velocity, etc., experienced on the surface of the earth, whereas the term climate is used to describe the long-term observed, averaged data for any of the weather components for a particular time period which can also be several decades.

Weather may vary from day to day or week to week, whereas climate varies from season to season or year to year. Climate is dynamic by nature. It is highly influenced by a multitude of factors such as the change in earth's orbit, gaseous composition of the earth's atmosphere, changes in the surface of the earth, and human activities.

Natural and man-made activities are much influenced by weather and climate. The seasonal variation in the surface air temperature is important for understanding the impact of climate change on human activities.

1.1 Climate Change

The earth's climate, by nature, is a complex system consisting of oceans, atmosphere, land surface and vegetation, which respond to influences of various time scales. Oceans are generally influenced on time scales of years to centuries, whereas atmosphere, which is defined as a blanket of air surrounding the earth, may change on a daily basis and vegetation changes on a seasonal time scale.

Earth experiences changes in its climate continuously. Due to enormous increase in population and the advancement in the technology founded on carbon-based fuels there has been a significant change in global climate. Climate change is directly linked to the increase in the green house gas concentration, caused by human activities (IPCC, 2001a).

Climate change does not necessarily mean that all regions experience a uniform change with respect to the direction and magnitude, but there may be regional variations. Also climate change may not imply that all successive years will necessarily have the same trend of increase or decrease.

Knowledge of daily weather data is helpful in many applications in day-to-day life. Weather data is generally needed in the design of many hydraulic structures, estimation of the quality and availably of water for domestic purposes and also for the proper planning of alternative crop management strategies. Overall weather data is useful for agricultural, irrigation and domestic purposes.

1.2 Effects of Climate Change

Prediction of weather is important because it gives us a snap shot picture of climate which is helpful in many ways. It helps agriculture, industries, and long term planning of hydraulic structures and also in planning large domestic construction projects, such as roads, bridges, etc. Furthermore it is helpful in quantifying global warming and in mitigating it.

Until recent years green house gases in the atmosphere were attributed primarily to the emission of carbon dioxide generated by fuel, but in recent years the role of trace gases has been recognized to be equally important. The knowledge about the change in temperature offers an insight into the impact of increasing CO_2 concentrations. Estimates of possible regional changes in the climate due to the increase of atmospheric CO_2 are required to evaluate the impact on various social and economic activities.

Global warming has become one of the most alarming issues these days. The global change adversely impacts terrestrial and aquatic ecosystems. Some of the most important economic resources, such as agriculture, forestry, fisheries, and water resources may also be affected. Increased temperature, severe and frequent droughts and floods, and sea level rise would have huge impacts on human life and economic well being.

Based on statistical evidence, the average global surface air temperature has increased by 0.6^0C between 1860 and 2000 (IPCC, 2001b). The increased global carbon dioxide emissions are mainly due to the energy burnt to run automobiles, power factories and heat homes and businesses.

Measurements of seasonal variations in the surface air temperature are important for better understanding of the impact of climate change on human activities. Although natural factors may have contributed to the temperature increase in the 20^{th} century, studies indicates that warming in the last 50 years may be due to increases in the green house gas concentration (Elaine and Rick, 2000). The major contributing factor for the climate change may be anthropogenic changes, which result in the decrease in the extent of snow cover and sea-ice thickness. Direct information can also be obtained from the instrumental records, such as average temperature. It is also noted that due to the thermal expansion of oceans, over the past century, global average sea level has been increasing by about 1 to 2 millimeter per year (Elaine and Rick, 2000).

Even without the influence of anthropogenic factors climate may vary from year to year due to natural reasons, such as volcanic eruptions. In the past, the main reason for the change in the ecosystem was considered to be the human intervention, but now the influence of climate change on the ecosystem has been established (Beaubien and Freeland, 2000).

1.3 Evaluation of Climate Change

The most reliable tool for estimating change in the atmosphere is General Circulation Models (GCMs). General Circulation Models are numerical models that analyze the atmosphere on an hourly basis in all three spatial dimensions based on the law of conservation of mass, momentum and conservation of water vapor. These models are complex computer simulations describing the circulation of air and ocean currents and how the energy is transported within a climate system. The best available GCMs for estimating the climate show that the annual global surface air temperature may increase at a rate of 2.5^0 to 4.5^0K due to the doubling of carbon dioxide concentration in the atmosphere (Grotch and MacCracken, 1990).

To get a broader idea of the climate change and its impacts in Louisiana, we consider the impacts of extreme climate events that are described by the Intergovernmental Panel on Climate Change (IPCC) for North America. Some of them are listed below:

1. There is a possibility of having more hot days and higher temperatures in almost all land areas.
2. There is a possibility of having a few cold days and very low minimum temperatures in almost all land areas.
3. There is a greater risk to natural ecosystems and wetlands due to these changes.
4. Due to the increase in sea level, there will be greater potential loss of land erosion due to and flooding resulting in the damage of wetlands in coastal areas.

With increasing global warming, people are concerned about these effects on local areas. Some of the basic observations, such as daily maximum and minimum temperatures and daily precipitation, sometimes have localized features that may be difficult to produce with the current coarse spatial resolution of the GCMs.

Many of these shortcomings can be overcome by considering local topography and regional geography. By observing the local climate and comparing it with the output of GCMs, we can improve the capabilities of current GCMs and have an understanding the local climate.

Considerable attention is given to test the ability of GCMs to reproduce the observed data. The very important issue concerning this verification is the ability of GCMs to reproduce observed regional and local climates. Some of the difficulties in comparing the local climate with the climate generated from the GCMs control run are:

1. Since local surface based observations are highly influenced by the local topography and geography, it is difficult to relate them.
2. There is always an uncertainty in the interpretation of the area represented by a GCM output at a grid point.
3. GCMs filter the important spatial discontinuities in the surface boundary due to coarse spatial resolutions.

For these reasons, it is important to understand the climate change on a local basis. In spite of the above difficulties, there are reasons why comparisons between the outputs of a control run from GCMs and the local observed data should be made. These reasons are:

1. Improved GCMs will give us a better understanding of their ability to reproduce local climate.

2. The impact of climate change occurs due to certain technological and socio-economic issues, which are specific to local areas.
3. It is important to understand how well GCMs reproduce day-to-day weather transitions, which can be more accurately accomplished considering daily variations in the local weather.
4. As of now the validation has been confined to large-scale features and larger time scales. However, there is a growing need for this kind of information on smaller regional scales.

Atmospheric events have a range of spatial and temporal scales. Meteorological variables, such as temperature, precipitation, and wind, at a particular location normally vary around the mean values from year to year, if they are not influenced by external agents, such as anthropogenic changes in the composition of the atmosphere.

Generally, global models have larger spatial resolutions of several hundred kilometers. The range of increase of temperature is estimated on a global scale but the range in increase of temperature varies drastically when applied to a smaller spatial feature. Hence there is a need for the regional estimation of various weather parameters. As there is a need to simulate global climatic features, it is advantageous to have smaller regional scale changes to assess the potential impact of climate change.

The basic step for any study connected with the future climate should have a thorough analysis of current climate conditions and the possible variability. Many times current climate is referred to as the base line climate, which is taken as a 30-year reference climate defined by the World Meteorological Organization (WMO). This base line climate is important for many reasons, some of which are:

1. The ongoing trends in the climate can be easily identified.
2. Knowing the prevailing conditions helps us to adapt some of the most likely features for future design.
3. The base line climate is useful to describe the average conditions, spatial and temporal variability and extreme events that have occurred.

1.4 Objectives of Study

Louisiana's Mississippi River delta contains the largest wetlands in the nation. These coastal wetlands support approximately 30% of national commercial fish and shellfish harvests. Tropical storms strike the Louisiana coast once in every four years on an average. As a result, many of the coastal wetlands are damaged and so also are the coastal aquatic systems. There is also an alarming rate of nearly 60 acres of loss for the wetlands per day due to increase in sea level, human interference with coastal processes and land sinking.

Due to changes in global climate, impacts can be felt on human health and terrestrial aquatic ecosystems. This could result in serious social-economic consequences if this trend continues. There is therefore an urgent need to study the regional climate impacts, particularity for the coastal regions of Louisiana.

Various measures are being implemented in Louisiana to protect coastal wetlands, reduce brown marsh problems and protect coastal aquatic life from the present and future danger. To make this study more effective one needs to have a clear idea about the future trends in climate.

The main objectives of this study are to predict the future climate for coastal Louisiana on a very fine scale making use of the existing GCMs and downscale these results to a finer scale using an empirical/statistical techniques in order to study regional climate impacts on Louisiana.

CHAPTER 2: LITERATURE REVIEW

In order to study regional changes in climate one needs to run Regional Climate Models (RCMs). RCMs are normally statistically nested with GCMs and run on very finer spatial and temporal scales.

RCMs are extremely computationally intensive and have data requirements which may not be easily available. Another way which is much more computationally efficient is the stochastic downscaling method. This is achieved by statistically downscaling GCM monthly predicted values using statistical methods. The daily statistics from observed data are used to derive statistical quantities, such as mean, standard deviation, skewness, etc. In this study a stochastic weather generator called CLIGEN is used for temporal downscaling.

2.1 Stochastic Weather Generator

Synthetic generation of weather data is useful in the regions where there is scarcity of data or a significant amount of data is missing. For generating such data stochastic weather generators are used.

A Stochastic weather generator (SWG) is a numerical or probabilistic model used to generate daily weather series, which are statistically identical with the observed data. The main purpose of a stochastic weather generator is to generate long time series, which are useful for risk assessments. The various advantages and disadvantages associated with the use of stochastic weather generators are briefly summarized below.

2.1.1 Advantages of SWGs

- An SWG has the ability to generate time series for an unlimited length of time.

- An SWG provides an opportunity to obtain representative weather time series in regions of scarce data by interpolating observed data
- An SWG gives the opportunity to alter the weather generator's parameters in accordance with the future climate change scenarios.
- SWG techniques may be able to provide more realistic scenarios of climate change at individual sites than the application of GCMs derived scenarios to an observed climate data set
- These techniques require fewer computations compared to the physical downscaling using numerical models.
- Ensembles (Ensemble simulation means that a number of runs with identical forcing, but with different initial conditions, are performed) of high-resolution climate scenarios may be produced relatively easily.

2.1.2 Disadvantages of SWGs

- An SWG is designed for the use of individual locations independently, and takes little account of spatial correlation of climate.
- An SWG sometimes is not able to accurately describe all aspects of climate, especially persistent events, rare events and century scale variations.
- Large amounts of observational data may be required to establish statistical relationships for the current climate.
- Specialist knowledge may be required to correctly apply the techniques.
- The relationships established using SWGs are only valid within the range of data used for calibration, which may not be an appropriate way since future projections for some variables may lie outside this range.

- It may not be possible to derive significant relationships for some weather variables using stochastic weather generators.
- Sometimes a predictor variable that may not appear as a significant factor when developing the transfer functions under present climate may become critical for determining the climate change.

There exists a multitude of stochastic weather generators. Some of the commonly used ones are:

- WGEN (Weather Generator) (Richardson and Wright 1984)
- USCLIMATE (US Climate) (Hanson et al. 1994)
- CLIGEN (Climate Generation) (Nicks et al. 1995)
- GEM (Generation of Weather for Multiple Applications) (Johnson 2001)

A brief description of the four common Stochastic Weather Generators is given below.

2.2 Weather Generator (WGEN)

WGEN is a computer simulation model that provides daily values for precipitation, maximum temperature, minimum temperature, and solar radiation for multi-year periods at a given location. The occurrence on a given day has a major influence on temperature and solar radiation for the day. Precipitation is generated independently of other variables. Maximum temperature, minimum temperature, and solar radiation are then generated according to whether a wet or dry day was previously generated. The model is designed to preserve the dependence in time.

The precipitation component of WGEN is a Markov chain gamma model. A first order Markov chain is used to generate the occurrence of wet or dry days. When a wet day is generated, the two-parameter gamma distribution is used to generate the precipitation amount.

The procedure used to generate daily values of temperature and solar radiation was described by Richardson (1981) and the procedure for generating weekly values was given by Matalas (1967). There are two major options available to generate:

1. Generate daily values for all four variables
2. Use actual precipitation data and generate the other three variables.

2.2.1 Advantages and Disadvantages of WGEN

The main advantage of this model is that it has become the basis for GEM that is a powerful tool for generating various components of weather for a high degree of accuracy. Also the weather generated from this model is close to true values. The disadvantage of this model is it can generate only four weather components, precipitation, maximum temperature, minimum temperature, and solar radiation for a particular day.

2.3 USCLIMATE

USCLIMATE is a computer model that provides easy access to precipitation probabilities or simulated weather data for a location within a state or region. Daily weather data, including all the days in a leap year, can be simulated for most locations in the United States. This was developed using the WGEN (Richardson and Wright 1984) model.

Daily precipitation is described by a first-order Markov chain with precipitation amounts distributed as a mixed exponential distribution. In addition, data on daily maximum and minimum temperatures and solar radiation are simulated using a weakly stationary generating process first described by Matalas (1967) and adapted to daily weather by Richardson (1981). The seasonal variations of parameters are described by Fourier series providing a parsimonious model. Through an interactive microcomputer program, a user can access the information for a single station or can estimate weather characteristics.

This model is the basis for the development of GEM, which retains the basic internal structure of USCLIMATE and WGEN. USCLIMATE is a fully developed model where as improvements are still being made for GEM.

2.3.1 Advantages of USCLIMATE

The daily weather information available through USCLIMATE can be applied to many applications but is most useful as an input to other models that require daily precipitation, maximum and minimum temperature, and solar radiation data. Several water resource models require daily weather information that is not available for many locations in the United States but that can be simulated. Therefore, simulated weather data can be used to estimate hydrologic processes, such as runoff and erosion rates. Sequences of daily weather data can also be used as input for many other applications from estimating plant growth and chemical transport to developing farm and ranch management plans and helping improve knowledge of the climatology of the United States.

2.3.2 Shortcomings of USCLIMATE

The USCLIMATE model does not generate good data for minimum temperatures in the northern latitudes; it also generates inaccurate solar radiation data for wet days in northern latitudes and for dry days in areas such as southern Arizona.

2.4 Climate Generation (CLIGEN)

The Climate Generation (CLIGEN) is a stochastic weather generator that produces daily values of weather parameters, such as temperature, precipitation, solar radiation, wind velocity and direction of wind using simple statistical monthly measurements, such as mean, standard deviation, and skewness. Arlin Nicks and Gene Gander (1990) first developed this at the USDA Agricultural Research Service (ARS) lab in the mid 1990's. In this model daily parameter values are calculated using historic weather data and individual parameter files are expected to reproduce the historic data. Each parameter is generated independent of the other. CLIGEN generates nine weather variables from long term observed data. They are:

- Maximum Temperature
- Minimum Temperature
- Dew Point Temperature (TDP)
- Probability of Precipitation (today)
- Amount of Precipitation
- Time to Peak of rainfall
- Radiation
- Wind Direction
- Wind Velocity

A first–order two–state Markov chain is used to generate the occurrence of precipitation for a day given the condition of previous day being wet or dry. If a random number that is drawn from a uniform distribution for each day is less than the precipitation probability for the given previous day status, a precipitation event is predicted. For a predicted rain day, a skewed normal distribution is used to generate daily precipitation amounts for each month (Nicks and Lane, 1989). The probability of a wet day is defined by the following formula:

$$P(W) = \frac{P(W/D)}{1 - P(W/W) + P(W/D)}$$

Where

$P(W)$: Probability of a wet day

$P(W/W)$: Probability of a wet day followed by a wet day

$P(W/D)$: Probability of wet day followed by a dry day

The present day temperatures, maximum, minimum, and dew point temperatures are assumed to have normal distributions. Multiplying the standard normal deviation, either positive or negative by the parameter's standard deviation for the present month and adding its monthly mean generate the temperature values.

To generate solar radiation, a random standard normal variate is produced and multiplied by the monthly standard deviation. This value is multiplied by ¼ the difference between the monthly mean and theoretical maximum, and added to the monthly mean.

Wind speed is generated using skewness in addition to the mean and standard deviation, from 16 different directions, and the percent of time that it comes from each of those directions

2.4.1 Advantages of CLIGEN

- CLIGEN generates nine weather parameters (maximum temperature, minimum temperature, radiation, dew point temperature (TDP), probability of precipitation (today), amount of precipitation, time to peak radiation, wind direction, and wind velocity) from long term observed data.
- CLIGEN runs at 95 stations in the United States.
- CLIGEN permits the generation of a large number of long-term time series
- Among the commonly used stochastic weather generators, CLIGEN is the only one that generates internal storm patterns, which are needed by many physically based hydrological and natural resource models.

2.4.2 Shortcomings of CLIGEN

All the parameters, precipitation, maximum and minimum temperatures, and solar radiation, are generated independent of each other, which may not be realistic. This can however be justified since it is common for the models to be insensitive for minimum one weather parameter

It is mathematically sensible to analyze the standard normal deviates from which parameters are generated. They are purely mathematical artifacts. Since they are not measured, they have no associated level of precision

2.4.3 Features of Improved Version of CLIGEN

- A very high quality run for uniform random distributions
- Better quality control for normal random distributions
- Command line options
- Three types of interpolation

- File names can include spaces, slashes and can be up to 256 characteristics
- Saves command line in output file

2.5 Generation of Weather Elements for Multiple Applications (GEM)

GEM was developed by the USDA-ARS, Northwest Watershed Research Center in Boise, Idaho, and USDA-NRCS, National Water and Climate Center, Portland, Oregon. GEM has the basic internal structure of the USCLIMATE (Hanson et al.1994; Johnson et al.1996) and WGEN (Richardson and Wright 1984) models, but several significant improvements have been made to this model.

GEM generates daily time series of various weather components, such as precipitation, maximum air temperature, minimum air temperature, solar radiation, average daily dew-point temperature, and average wind speed. The main purpose of producing these time series is to statistically represent the weather that can be expected at a particular location over a period of time.

A first order Markov chain describes precipitation component, with the amounts distributed as mixed exponential distribution. The other parameters, such as daily maximum and minimum temperatures, solar radiation and wind speeds, are simulated using Fourier series.

2.5.1 Advantages of GEM

The main advantage of this model is that the climate generated from the GEM model is close to the true climate in almost all aspects. The other advantage which makes this model more attractive over other models is PRISM (PRogramme for Integrated earth System Modelling), developed at Oregon State University for the spatial distribution, which means that the representative weather scenarios can be developed for any location, even in the regions with limited climate data.

2.5.2 Shortcomings of GEM

GEM predicts only four weather variables: precipitation, maximum temperature, minimum temperature and solar radiation.

2.6 General Circulation Models

2.6.1 History of GCMs

The idea of mathematically simulating atmospheric motion, to aid the forecast of weather, was first started in the 1920s. But the numerical weather forecasting became very practical in the 1950s using electronic digital computers. Towards the end of the 1950s weather forecasters in United States and some parts of Europe incorporated computer-generated weather maps into their work on a routine basis. In the 1960s, with the increase in the computer power, it was possible to go beyond regional weather simulations to model the global general circulation. This helped scientists to simulate climate over very long periods.

By the 1970s, General Circulation Models (GCMs) had become a very important tool of climate science. During that time, scientists became concerned about the long-term possible effects of carbon dioxide accumulation in the atmosphere, which resulted in the study of anthropogenic (human-induced) global climate change. GCMs simulations provided a crucial means of analyzing the effects of climate change.

Meanwhile, ocean modelers started to build similar computer simulations of the Oceanic General Circulation Models (OGCMs). Since oceans are a major component of the overall climate system, climate modelers began trying to "couple" OGCMs with atmospheric GCMs. Although there were some difficulties in coupling these models, by the middle of the 1980s, these coupled models had established a new standard for climate modeling.

In the 1980s, scientific concerns led to international political negotiations over how to respond to the possible climatic changes. A global body of climate scientists, the Intergovernmental Panel on Climate Change (IPCC), was formed to provide scientific advice to these negotiations. In 1992, most of the world's nations signed the United Nations Framework Convention on Climate Change (FCCC). After several meetings FCCC focused on the ways to reduce the emissions and also in other ways of mitigating the effects of climate change.

GCMs have thus played a major role not only in advancing the atmospheric science but also in creating global awareness of a possibly serious threat to human civilization.

2.6.2 Definition of GCM

A general circulation model is a numerical model that gives the analysis of atmosphere on an hourly basis in all three spatial dimensions based on conservation laws of momentum, energy and water vapor.

GCMs are the most reliable and powerful tool for estimating the changes in the climate. These are also known as global climate models, generally abbreviated as GCMs. These are also the complex computer simulations that describe the circulation of air and ocean currents and also how the energy is transported within a climate system. These are mathematical representations of atmospheric and oceanic properties and processes that help describe the earth's climate system.

These are also computer models used to enhance our understanding of the factors that influence climate and improve our ability to predict future climate patterns.

The main objective of a typical general circulation model is to predict climate having a spatial coverage with a temporal scale of years, having a very coarse spatial resolution, low relevance of initial conditions, having a high relevance of clouds, radiation, surface, ocean dynamics, and model stability.

2.6.3 Features of GCMs

The main features of General Circulation Models are

- The main goal is to predict the future climate.
- They have a global spatial coverage.
- They have a temporal range of years to centuries.
- They have a very coarse resolution of several hundreds of kilometers.
- They are based on the conservation laws for mass, momentum, energy and water vapor.
- They are controlled by spatial resolution.
- The method used to run GCMs is finite difference expression of continuous time and space equations, or a spectral representation.

Global climate models are the only powerful tools currently available for simulating the response of the global climate system to the increasing greenhouse gas concentrations. These three-dimensional models of the atmosphere and ocean have been used to investigate the effects of changes in the atmospheric composition on the global climate. The more recent GCMs are able to differentiate between the warming effect of greenhouse gases and the regional cooling effect of sulphate aerosols.

Sulphate aerosols affect climate directly through the scattering and absorption of solar radiation and also by altering the properties and lifetime of clouds, which ultimately cool the earth's surface. Currently, the available GCMs only have the direct effects of sulphate aerosols. Unlike greenhouse gases, sulphate aerosols have a relatively short atmospheric lifetime.

Sulphate aerosols are produced mainly in industrial regions and depending upon atmospheric conditions they may be rained out in a matter of days. To model the atmospheric effects of sulphate aerosols adequately, GCMs must be able to reproduce the geographical variation in their atmospheric concentration. Patterns of aerosol emission can vary immensely from season to season and decade to decade, depending on the sources and volumes of sulphate emissions.

Many GCM experiments are now available for use in climate change studies. There is a large library of equilibrium GCMs experiments available for use (http://ipcc-ddc.cru.uea.ac.uk). For the impacts and those who are unfamiliar with GCM studies, the choice of experiments is large and most likely confusing. Even for the familiar it will be confusing to decide the right experiment to choose. For this reason Smith and Hulme (1998) put forward a number of criteria to guide the selection of GCM experiments:

- **Vintage:** Simulations taken from a more recent model are likely to be more reliable than those from the earlier ones, since they will be based on the current knowledge involving more processes and feedbacks and will usually have a higher spatial resolution than the earlier models.
- **Resolution:** GCM resolutions have been becoming finer with time due to the advances in computing technology and also with more recent models having

spatial resolutions of the order of 250 km and about 20 vertical levels, compared to a resolution of about 1000 km and between 2 and 10 vertical levels in earlier GCMs. Sometimes, though the recent models contain more spatial details, better boundary conditions and more complex topography, they may not necessarily have high performance compared to the previous ones.

- **Validity:** The very important factor to be considered in the selection of GCMs is the model performance that is the selection of GCMs that simulate the present day climate more accurately. It is generally assumed that these GCMs are the most reliable representation of the future climate. Though statistical methods can be employed to compare the mean values, variability and climatic patterns of the observed data and model results for the current baseline period, still the choice of GCM, will much depend on the region of interest. The relative performance of GCMs depends critically on the size of the region, on its location and on the variables to be analyzed. It must also be noted that comparisons between observed data and model results should take place at the resolution of the model, rather than at the resolution of the observed data set. GCMs operate at a particular spatial resolution and they cannot be expected to capture the features of climate, which occur at the sub-grid scale. Hence, some ‘upscaling’ of the observed data is necessary, that is, the construction of observed regional climates from station data. Rather than trying to identify the model, which simulates current climate most accurately, a better approach may be to identify those models whose performance is unacceptably poor, particularly in the estimation of climatic features which are of critical importance to the impact application. A number of international model intercomparison projects currently exist, in which specific components of different GCMs are compared in order to determine why model performance may not be particularly good in some cases.

- **Representative ness of Results:** It is strongly recommended that more than one GCM is used in any impact assessment and the selected GCM should show a range of changes in a key climate variable (e.g., temperature, precipitation) in the study region. At the regional level GCMs can display large differences in their estimates of climate change, particularly for variables, such as precipitation where one model will indicate wetter conditions while another will show significant drying in the study region. It is important to try and capture this range of future climate conditions in any assessment of climate change impacts.

The IPCC-TGCIA (Task Group on Scenarios for Climate Impact Assessment) made use of these criteria to decide which GCM experiments would be archived and made available through the Data Distribution Center (DDC). The experiments available from the DDC therefore reflect state-of-the-art model experiments and provide a representative range of results from different GCMs. The experiments available from the DDC have the following characteristics:

- An IS92a-type forcing scenario (results obtained from GCM runs, based on the IPCC-IS92a or similar emission scenarios) has been used.
- Integration with and without sulphate aerosol forcing is available and for greenhouse gas only forcing the simulations extends to 2100.
- Results are available now and data are lodged in public domain.
- Documentation exists, including journal articles.

The models have been included in model intercomparison exercises, such as the Atmospheric Model Intercomparison Project (AMIP) and the Coupled Model Intercomparison Project (CMIP).

On the basis of these criteria, the IPCC-TGCIA selected a number of experiments from seven international climate-modeling centers. Hence, the experiments available from the DDC should be used first of all in any impact assessment since they meet both the TGCIA criteria and those proposed by Smith and Hulme (1998).

2.6.4 Sources of Climate Change Scenarios Derived From the GCM Output

The IPCC-DDC (**http://ipcc-ddc.cru.uea.ac.uk**) archives climate change scenarios constructed from the GCMs experiments undertaken at seven international modeling centers. These are as follows:

- Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO)
- Deutsches Klimarechenzentrum DKRZ, Germany
- Hadley Center for Climate Prediction and Research HCCPR, UK
- Canadian Center for Climate Modeling and Analysis (CCCma)
- Geophysical Fluid Dynamics Laboratory GFDL, USA
- National Center for Atmospheric Research (NCAR), USA
- Center for Climate Research Studies (CCSR), Japan and National Institute for Environmental Studies (NIES), Japan

The data set for each GCM experiment consists of monthly values for eight surface variables: precipitation rate, mean sea level pressure, solar radiation, mean air temperature, dew point temperature, minimum air temperature, maximum air temperature and 10m wind speed. If a particular variable in this list was unavailable, it means it has been replaced with a similar variable, for example in some cases vapor pressure or relative humidity has replaced the dew point temperature. All the scenarios available from the DDC are at the global scale.

For the purpose of deriving finer resolution climate from a coarser resolution output spatial downscaling technique is used.

2.7 Spatial Downscaling

Spatial downscaling is a technique by which finer resolution climate information is derived from coarser resolution GCM output. The basic assumption of spatial downscaling is that it is possible to derive significant relationships between local and large-scale climates. Since the spatial resolution of current GCMs is between 250 and 600 km and as the forcing that affects regional climate occurs generally at a very finer spatial scale when compared to GCMs, it may lead to a significantly different regional climate conditions compared to larger spatial scales. Spatial downscaling techniques can be divided mainly into empirical/statistical methods and statistical/dynamical methods.

2.7.1 Empirical/Statistical Methods and Statistical/Dynamical Methods

These techniques refer to a method in which sub-grid scale changes in climate are calculated as a function of large-scale climate. Statistical relationships are calculated between large area and site-specific surface climate, or between large scale upper air data and local surface climate. Stochastic weather generators may also be conditioned on the large-scale state in order to derive site-specific weather. The fundamental assumption behind all these methods is that the statistical relationships, which are calculated using observed data, will remain valid under future climate conditions.

There are several different methods, which can be used to derive the relationship between local and large-scale climates. There is no standard method used for spatial downscaling, though mostly multiple linear regression, principle component analysis, and artificial neural networks are used, however the selection procedure mainly depends on the project objective. Whatever method is considered, the resulting function should show a large variability between a larger scale and a regional scale. Verification of the results using statistical methods should be undertaken, which can be done either by predicting from 10 years of known data and going further into future or predicting for a station with known historic data and performing the statistical analysis between the original and predicted climate. Once the model calibration and verification process gives satisfactory results, then the statistical models may be used for climate change studies.

The downscaling procedure using statistical/dynamical techniques is very similar to that described above for empirical/statistical methods. In this case weather types, or atmospheric circulation patterns are used rather than the large-scale predictor variables and statistical relationships between the types or patterns, and observed station data are calculated.

2.7.2 Advantages of Empirical/Statistical Methods

- Spatial downscaling techniques provide more realistic scenarios of climate change at individual sites than the straight application of GCM-derived scenarios to an observed climate data set.

- These techniques are much computationally demanding than the physical downscaling using numerical models.

2.7.3 Disadvantages of Empirical/Statistical Methods

- Large amounts of observed data may be required to establish statistical relationships for the current climate.
- Specialist knowledge may be required to apply the techniques correctly.
- It may not be possible to derive significant relationships for some variables.

CHAPTER 3: DATA DESCRIPTION

For the purpose of analysis a number of global models is used. Required data for the analysis was downloaded from IPCC (Inter Governmental Panel on Climate Change) data distribution center web site and also from CLIGEN (Climate Generation) model, which was produced by Arlin Nicks and Gene Gander (mid 1990s) at the USDA-ARS lab (United States Department of Agriculture-Agricultural Research Service).

3.1 CLIGEN

CLIGEN is a stochastic weather generator that produces daily time series estimates of precipitation, temperature, dew point, wind, and solar radiation for a single geographic point, based on average monthly measurements for the period of climatic record, such as means, SD's, and skewness. The two main important components of CLIGEN to generate the weather are data file (historic data) and parameter file (statistical input file). The parameter file is generated from the historic data and the weather generation is done using the parameter file. For convenience of the user a command line option was added to this model to generate the required weather data.

3.1.1 CLIGEN Input File

The parameter file is generated from historic data by some statistical analysis. The typical input parameter file from which the weather is generated is shown in Figure 3.1. Detailed description of each line and the format of each line are shown in the appendix A. All the input files in CLIGEN have a .par extension.

As the main focus of this study is on Coastal Louisiana a grid convention system was developed dividing Louisiana into a latitude-longitude grid with a grid spacing of one-degree latitude by one-degree longitude. Therefore the required grid is of size 7(i) by

```
ALEXANDRIA LA                          16  98 0
LATT=  31.32 LONG= -92.55 YEARS= 63. TYPE= 4
ELEVATION =   80. TP5 = 3.43 TP6= 7.93
MEAN P    .51   .55   .58   .63   .67   .55   .48   .46   .47   .71   .66   .62
S DEV P   .60   .68   .75   .93   .84   .76   .72   .62   .69  1.13   .89   .84
SKEW  P  1.92  2.64  2.26  3.37  2.36  3.50  5.97  2.88  3.09  3.24  3.96  3.06
P(W/W)    .46   .45   .39   .41   .47   .44   .48   .44   .50   .44   .43   .48
P(W/D)    .27   .25   .24   .21   .19   .18   .24   .21   .16   .12   .19   .25
TMAX AV 59.24 63.38 70.30 78.08 84.63 91.01 92.87 92.89 88.38 80.44 69.39 61.87
TMIN AV 38.60 41.82 48.10 56.10 63.47 69.99 72.40 71.72 66.64 55.26 46.07 40.58
SD TMAX 11.94 10.93  9.37  6.97  5.37  4.59  4.19  4.20  6.05  7.39  9.64 10.65
SD TMIN 11.42 10.49  9.96  8.43  5.99  4.19  2.63  3.18  6.45  9.23 10.51 10.66
SOL.RAD  238.  289.  368.  434.  514.  521.  522.  490.  414.  367.  273.  214.
SD SOL   54.4  68.8  82.7  99.4  96.7 105.7  99.7 225.0  91.5  50.6  47.7  53.4
MX .5 P  1.07  1.02  1.21  1.43  1.96  1.13  1.47  1.83  2.10  1.32  1.18  1.09
DEW PT  42.91 44.91 48.22 56.45 64.14 70.07 72.39 71.76 67.45 56.76 47.83 43.22
Time Pk   .461  .586  .654  .735  .767  .791  .829  .846  .875  .912  .950 1.000
% N      10.06  7.85  6.31  4.65  4.87  3.17  3.56  4.24  7.93  8.05  8.03  8.42
MEAN      4.86  4.77  4.60  4.48  4.10  3.32  3.27  3.04  3.66  4.15  4.52  4.56
STD DEV   2.03  2.06  1.87  1.83  1.72  1.31  1.12  1.10  1.49  1.88  1.84  1.94
SKEW       .73   .54   .52   .49   .76   .72   .52   .78   .90   .80   .43   .61
% NNE     8.06  5.73  4.83  3.71  3.90  2.91  2.63  3.94  8.05  7.52  6.72  6.16
MEAN      4.46  4.70  4.41  4.12  4.00  3.23  3.09  3.06  3.56  4.01  4.15  4.12
STD DEV   1.74  1.89  1.82  1.65  1.63  1.10  1.11  1.16  1.36  1.79  1.73  1.62
SKEW       .44   .50   .61   .40   .86   .57   .71  1.09   .75   .84   .61   .58
% NE      6.46  5.87  5.52  3.89  4.37  3.78  3.08  4.59  8.59  6.70  5.84  5.96
MEAN      3.84  4.19  4.16  4.06  3.73  3.37  3.39  3.15  3.48  3.56  3.61  3.96
STD DEV   1.54  1.60  1.66  1.64  1.46  1.26  1.23  1.07  1.34  1.47  1.39  1.45
SKEW       .74   .51   .69   .71   .73   .70   .80   .84   .71   .77   .77   .56
% ENE     4.48  5.12  4.35  3.90  4.27  3.67  2.80  5.19  7.54  4.47  3.16  4.71
MEAN      3.74  4.02  4.08  3.92  3.69  3.34  3.36  3.24  3.66  3.36  3.45  3.75
STD DEV   1.64  1.56  1.60  1.38  1.30  1.21  1.18  1.28  1.49  1.25  1.40  1.45
SKEW      1.00   .61   .78   .55   .41   .70   .34  1.04   .88   .60  1.13   .73
% E       4.73  5.11  5.25  4.40  5.30  5.58  4.94  6.49  7.57  5.79  3.56  4.74
MEAN      3.45  3.70  3.69  3.48  3.54  3.14  3.31  3.19  3.52  3.07  3.36  3.31
STD DEV   1.52  1.47  1.38  1.40  1.22  1.09  1.26  1.18  1.38  1.12  1.38  1.23
SKEW      1.14   .69   .60   .85   .59   .50   .88   .98   .89   .75   .79   .80
% ESE     4.21  3.68  3.70  3.37  4.70  4.30  3.72  4.41  5.42  4.70  3.98  4.15
MEAN      3.41  3.56  4.20  3.77  3.49  3.32  3.38  3.12  3.34  3.43  3.38  3.53
STD DEV   1.22  1.44  1.70  1.45  1.34  1.18  1.28  1.34  1.27  1.29  1.20  1.33
SKEW       .72   .74   .95   .61   .57   .79   .77  1.39   .67   .91   .83   .61
% SE      5.51  4.46  5.33  7.01  6.23  5.22  4.45  4.61  5.71  5.41  5.39  5.73
MEAN      3.82  4.18  4.36  4.35  3.97  3.56  3.34  3.35  3.41  3.66  3.97  3.99
STD DEV   1.54  1.72  1.79  1.88  1.55  1.29  1.29  1.36  1.34  1.43  1.60  1.76
SKEW       .65   .81   .72   .82   .58   .66   .77   .80  1.03   .90   .96   .92
% SSE     5.08  4.44  6.63  9.09  7.43  5.48  4.09  3.83  3.18  3.57  5.52  5.44
MEAN      4.06  4.64  4.58  4.87  4.49  3.94  3.30  3.31  3.65  3.99  4.42  4.35
STD DEV   1.48  1.99  1.83  1.84  1.63  1.56  1.27  1.29  1.52  1.65  1.77  1.72
SKEW       .43   .86   .70   .55   .34   .56   .98   .80   .87   .68   .58   .58
% S       9.89  9.31 14.69 20.50 14.91 13.23  9.01  7.88  6.35  4.62  9.37  9.21
MEAN      4.66  5.13  5.27  5.12  4.63  4.11  3.41  3.26  3.55  3.60  4.41  4.54
STD DEV   1.95  2.21  2.06  1.97  1.77  1.67  1.33  1.22  1.38  1.54  1.87  1.92
SKEW       .76   .68   .48   .53   .49   .81   .97  1.04   .78  1.04   .72   .69
% SSW     4.75  4.99  6.31  7.82  7.11  7.74  6.99  5.84  2.48  2.52  4.01  3.98
MEAN      4.71  4.99  5.10  5.08  4.51  3.93  3.58  3.43  3.44  3.57  4.37  4.21
STD DEV   1.90  2.20  1.99  1.91  1.71  1.45  1.26  1.26  1.37  1.38  1.97  1.92
SKEW       .69   .61   .45   .28   .34   .54   .58   .68   .53   .55   .76   .91
% SW      2.84  3.75  3.65  3.87  5.10  5.77  8.15  5.13  2.19  2.09  2.31  2.83
MEAN      4.65  4.16  4.23  4.53  3.91  3.67  3.46  3.29  3.28  3.34  4.20  4.05
STD DEV   2.09  1.85  1.72  1.89  1.53  1.40  1.30  1.28  1.35  1.44  2.09  1.68
SKEW       .49   .69   .50   .53   .69   .73   .68  1.15   .63  1.08   .85   .84
% WSW     2.28  2.92  2.40  1.95  2.35  4.58  6.39  4.20  1.49  1.28  1.76  1.95
MEAN      3.94  4.01  4.12  3.78  3.53  3.34  3.43  3.43  3.18  3.14  3.50  3.56
STD DEV   1.80  1.66  1.74  1.72  1.41  1.31  1.24  1.32  1.18  1.06  1.53  1.48
SKEW       .84   .62   .65   .61   .53  1.08   .51   .75   .65   .44  1.03   .94
% W       2.54  3.82  3.49  2.23  2.33  4.22  6.57  4.89  2.15  2.42  2.40  3.25
MEAN      4.04  4.20  4.55  3.36  3.25  3.55  3.36  3.15  3.06  3.78  3.63  3.74

INTERPOLATED DATA (station & weighting factor)

---Wind Stations---
ALEXANDRIA    LA     .647  FT.POLK       LA     .233  LAKE CHARLES  LA     .119
---Solar Radiation and Max .5 P Stations---
BATON ROUGE, LOUIS  .413   SHREVEPORT, LOUISI  .375   GALVESTON, TEXAS    .212
```

Figure 3.1: Table showing the format of an input parameter file

by 5(j), where ‘i’ denotes longitude and ‘j’ denotes latitude. The grid definition is explained with an illustration is shown in Section 3.1.2.

3.1.2 Grid Definition

i = columns (longitudes), i goes from left to right (-94.5^0 to -88.5^0)

j = rows (latitudes), j goes from top to bottom (31.5^0 to 27.5^0)

29 31.5, 94.5	**30** 31.5, 93.5	**31** 31.5, 92.5	**32** 31.5, 91.5	**33** 31.5, 90.5	**34** 31.5, 89.5	**35** 31.5, 88.5
28 30.5, 94.5	**27** 30.5, 93.5	**26** 30.5, 92.5	**25** 30.5, 91.5	**24** 30.5, 90.5	**23** 30.5, 89.5	**22** 30.5, 88.5
15 29.5, 94.5	**16** 29.5, 93.5	**17** 29.5, 92.5	**18** 29.5, 91.5	**19** 29.5, 90.5	**20** 29.5, 89.5	**21** 29.5, 88.5
14 28.5, 94.5	**13** 28.5, 93.5	**12** 28.5, 92.5	**11** 28.5, 91.5	**10** 28.5, 90.5	**9** 28.5, 89.5	**8** 28.5, 88.5
1 27.5, 94.5	**2** 27.5, 93.5	**3** 27.5, 92.5	**4** 27.5, 91.5	**5** 27.5, 90.5	**6** 27.5, 89.5	**7** 27.5, 88.5

For each latitude-longitude grid point, five closest stations to all the central grid points are selected using Great Circle Distance formula (Section 4.5.1). Using the Inverse Distance Weighted Interpolation (Section 4.5.2) all the values for the central grid is found. All these files are stored under a folder name ‘base’, which is stored in a folder named ‘ipcc’.

3.1.3 Weather Generation Using CLIGEN

For convenience of the user a command line option is given. The command used in the command prompt is **‘-b1970 –y30 -iLa160098.par -oLa160098_test1.par’**, where **‘b’** indicates the beginning year from which we need the data, **‘y’** indicates number of years of simulation, **‘i’** denotes the input file, **‘o’** denotes the output file where the generated data is stored. When the command is executed it gives five options to choose from. For all our analysis purposes we chose option 5, which is a multiple year WEPP (Water Erosion Prediction Project) output file.

3.1.4 Details of Output Files

The output obtained will have the details of the station name, version of CLIGEN used to get the output, latitude, longitude, elevation, begin year, number of years simulated and the command line and the observed monthly averages of maximum temperature, observed monthly minimum temperature, observed monthly average solar radiation, and observed monthly precipitation values. The example of the output file is shown in figure 3.2.

3.2 Global Climate Models

3.2.1 Introduction

There are seven major centers modeling the global data given in Chapter 2. The Data Distribution Center (DDC) of the Intergovernmental Panel on Climate Change (IPCC) has been established to facilitate the timely distribution of a consistent set of up-to-date scenarios of changes in climate and related environmental and socio-economic factors for use in climate impact assessments.

The IPCC Data Distribution Center takes into consideration the research results from seven climate modeling centers. We have selected the results from GCMs (General Circulation Model) runs based on IPCC-IS92a emission scenarios. There are six IS92 scenarios generated by the IPCC that describe how global energy might evolve over the next century if society did not take any action to deal with the climate change risks. IPCC-IS92a emission scenario of the IPCC estimates that the average annual increase of global carbon dioxide emissions by about one percent per year till 2100. For all the

```
5.111
   1   0   0
   Station:  ALEXANDRIA LA                                  CLIGEN VERSION 5.111 -r:    0 -
I: 0
 Latitude  Longitude  Elevation  (m)  Obs.  Years    Beginning  year   Years  simulated  Command
Line:
    31.32   -92.55   24   63  1976     60   -b1976 -y60 -iLa160098.par -oLa160098_test1.par
 Observed monthly ave max temperature (C)
  15.1  17.4  21.3  25.6  29.2  32.8  33.8  33.8  31.3  26.9  20.8  16.6
 Observed monthly ave min temperature (C)
   3.7   5.5   8.9  13.4  17.5  21.1  22.4  22.1  19.2  12.9   7.8   4.8
 Observed monthly ave solar radiation (Langleys/day)
 238.0 289.0 368.0 434.0 514.0 521.0 522.0 490.0 414.0 367.0 273.0 214.0
 Observed monthly ave precipitation (mm)
 133.9 122.2 128.9 126.0 139.2 101.9 119.4  98.8  86.8  98.7 125.7 158.5
 da mo year  prcp  dur   tp     ip  tmax  tmin  rad  w-vl w-dir  tdew
             (mm)  (h)               (C)   (C) (l/d) (m/s)(Deg)   (C)
  1  1 1976   0.0  0.00 0.00   0.00  12.7  10.6 331.  4.3   56.  11.4
  2  1 1976   0.0  0.00 0.00   0.00   7.5   2.4 135.  5.8  340.   4.7
  3  1 1976   0.0  0.00 0.00   0.00   9.7   8.8 206.  8.4  225.  -2.8
  4  1 1976   0.0  0.00 0.00   0.00  24.1   0.9 283.  3.9  204.  -2.4
  5  1 1976   8.3  6.13 0.33   9.47  14.6  -1.7 303.  0.0    0.   6.2
  6  1 1976   0.0  0.00 0.00   0.00  22.0   9.3 140.  7.7  224.  10.0
  7  1 1976   0.0  0.00 0.00   0.00   9.9   1.0 301.  4.5   22.   4.6
  8  1 1976   0.3  1.19 0.01   2.75  20.9  -4.2 349.  5.3  355.   5.6
  9  1 1976   2.8  8.39 0.07  17.42  15.3   6.8 216.  0.0    0.   7.6
 10  1 1976   0.0  0.00 0.00   0.00  17.8   6.1 267.  7.3   43.   9.2
 11  1 1976   0.0  0.00 0.00   0.00  17.7   2.4 313.  1.0    6.  -6.8
 12  1 1976   2.0  1.60 0.23   3.27  11.8  -1.6 217.  6.4  197.   4.9
 13  1 1976   2.6  3.40 0.02   4.24   9.2  -4.1 295.  0.0    0.   2.4
 14  1 1976   2.7  1.60 0.02   3.37   6.2   1.4 163.  0.0    0.   2.0
 15  1 1976   0.9  4.12 0.06   4.91   8.1  -4.9 285.  1.3   83.  -3.9
 16  1 1976  28.4  1.33 0.05   2.73  10.0   7.7 247.  6.3   13.   0.4
 17  1 1976   0.0  0.00 0.00   0.00  14.4   7.5 227.  0.0    0.   1.8
 18  1 1976   0.0  0.00 0.00   0.00  15.9   2.3 191.  4.4  284.   0.5
 19  1 1976   0.0  0.00 0.00   0.00  19.5   0.6 170.  4.2  310.   6.0
 20  1 1976  11.9  1.65 0.68   2.64   2.2   0.6 250.  4.1    6.  -3.8
 21  1 1976   0.0  0.00 0.00   0.00  21.5   1.4 322.  5.8  289.  10.4
 22  1 1976   0.0  0.00 0.00   0.00  12.7   3.8 124.  3.5  214.   5.9
 23  1 1976   0.0  0.00 0.00   0.00  18.7   1.2 184.  2.6   99.   7.6
 24  1 1976   0.0  0.00 0.00   0.00  11.4  -6.3 216.  3.4   87.  -5.4
 25  1 1976  50.1  3.95 0.08   7.36  19.8  -3.5 162.  0.0    0.   7.9
 26  1 1976   0.0  0.00 0.00   0.00  21.3   6.3 256.  4.2  107.  13.5
 27  1 1976   0.0  0.00 0.00   0.00  11.6   5.7 201.  3.5  141.   8.4
 28  1 1976   7.0  1.72 0.00   1.87  22.0  -5.6 163.  4.7  127.  -0.7
 29  1 1976   2.7  4.83 0.06  15.41  29.8   9.4 285.  3.6  182.   6.7
 30  1 1976  22.7  2.23 0.51   1.45  16.3   6.4 263.  3.0  315.   0.1
 31  1 1976   9.5  4.80 0.98   9.89  26.6  16.8 214.  2.8  230.  15.3
  1  2 1976  15.8  4.77 0.28   7.65   4.2  -0.2 222.  7.5  313.   1.8
  2  2 1976   0.0  0.00 0.00   0.00  13.1   3.1 340.  3.8   98.   2.8
  3  2 1976   0.0  0.00 0.00   0.00  13.6   9.8 324.  5.9   31.  11.6
  4  2 1976   3.1  8.49 0.02   9.84  21.7  -6.7 162.  4.1   47.  -4.4
  5  2 1976   0.0  0.00 0.00   0.00  29.9  11.3 357.  0.0    0.  10.7
  6  2 1976   5.7  3.67 0.27  17.22  18.0   4.3 331.  5.0  236.  10.8
  7  2 1976   0.0  0.00 0.00   0.00  20.2  11.1 278.  0.0    0.   6.8
  8  2 1976   0.0  0.00 0.00   0.00  12.4   4.8 204.  1.9   33.   8.5
  9  2 1976   0.0  0.00 0.00   0.00  21.3  14.2 337.  6.1  181.  -3.5
 10  2 1976   0.9  3.07 0.04   8.06  20.9   6.8 302.  1.5  260.  10.2
 11  2 1976   0.0  0.00 0.00   0.00  29.9   4.0 297.  6.3  207.  -2.6
 12  2 1976   0.0  0.00 0.00   0.00  18.5  -3.2 241.  4.7  235.   7.4
 13  2 1976   0.0  0.00 0.00   0.00  21.4   8.6 277.  3.1  269.   9.9
 14  2 1976  13.9  4.44 0.16   7.57  16.4  11.0 237.  5.6  184.   7.1
 15  2 1976  47.9  6.95 0.13   7.35  18.0  -1.5 314.  4.8   10.   3.8
 16  2 1976   0.0  0.00 0.00   0.00  13.1   1.5 280.  3.3    6.  -0.1
 17  2 1976   0.0  0.00 0.00   0.00  24.3   7.3 338.  5.4  290.  13.3
 18  2 1976   1.2  9.87 0.33  10.16  15.9   6.8 422.  2.3  223.  11.0
 19  2 1976   0.0  0.00 0.00   0.00  21.2   2.0 247.  2.1  109.   5.9
 20  2 1976   0.0  0.00 0.00   0.00  13.7   8.0 235.  4.9  257.   5.7
 21  2 1976   0.0  0.00 0.00   0.00  13.8   7.5 311.  0.0    0.   6.6
 22  2 1976   0.0  0.00 0.00   0.00  13.9   7.5 180.  2.1   80.  10.4
 23  2 1976   2.8  1.86 0.06   1.95  20.3   6.3 201.  4.7  248.   7.5
```

Figure 3.2: Figure showing the format of an output file

Models and all the runs in that model we downloaded the data is in ‘grib’ format. The widely used format that is used to represent forecast and analysis products is FM 92 GRIB. The World Meteorological Organization (WMO), through its Commission for Basic Systems (CBS) and Working Group on Data Management, maintains and reviews the GRIB specifications. To process GRIB data obtained from IPCC-DDC, Deutsches Klimarechenzentrum (DKRZ) provides software as a source code. “grbconv” is the program that either lists the contents of a GRIB file or converts GRIB records to binary or ASCII.

3.2.2 CSIRO

CSIRO is a globally coupled ocean-atmosphere-sea-ice model (CSIRO coupled). Atmospheric and oceanic components use a spectral R21 horizontal grid (each grid box measuring about 625 km by 350 km) with 9 vertical levels in the atmosphere and 21 levels in the ocean. The ocean model has a heat transport scheme, which significantly reduces problems associated with excessive mixing in the Southern Ocean. CSIRO uses a model called CSIRO-MK2. There are three experiments involved with this model. They are discussed below:

3.2.2.1 Control Integration

In this experiment the simulation is done over several hundred years of length keeping the atmospheric force constant. The IPCC Data Distribution Centre (DDC) distributes data of a 220-year period according to the length of the climate change experiments (the greenhouse gas and the greenhouse gas plus sulphate aerosol forcing runs) available from CSIRO. The various components on which the runs are made are:

- **Net surface solar radiation:** Net solar radiation at surface. Units are ‘W/m**2’

- **Mean sea level pressure:** Pressure, reduced to mean-sea level. Units are ‘Pa’
- **Precipitation*:*** Total Precipitation rate. Units are ‘mm/day’
- **2-meter temperature:** Temperature at 2 meter above ground. Units are ‘K’
- **2-meter maximum temperature:** Monthly maximum temperature at 2 meter above ground. Units are ‘K’
- **2-meter minimum temperature:** Monthly minimum temperature at 2 meter above ground. Units are ‘K’

3.2.2.2 Greenhouse Gas Integration

Here the greenhouse gas forcing is increased gradually to represent the observed changes in forcing due to all the greenhouse gases from 1881 to 1990. From 1990 to 2100 it uses an increase in concentrations represented by the IS92a emissions scenario. The various components on which the runs are made are same as the ones in Section 3.2.1.1

3.2.2.3 Sulphate Aerosol and Greenhouse Gas Integration

The forcing includes not only the greenhouse gas forcing described with the "greenhouse run" but also the direct radiative effect of sulphate aerosol concentrations. The various components on which the runs are made are same as the ones in Section 3.2.1.1

3.2.2.4 Grid Definition

The model resolution used here is abbreviated by the term 'R21' which corresponds to a horizontal resolution of 64*56 grid points. The grid orientation is west to east (latitudes), south to north (longitudes). The upper left and right corner, lower left and right corner are shown below

I=1, J=56 (0.00 E, 87.5613 N)	I=64, J=56 (354.3750 E, 87.5613 N)
I=1, J=1 (0.00 E, 87.5613 S	I=64, J=1 (354.3750 E, 87.5613 S)

For our analysis all the data is saved under 'csiro', which is under 'GCMs', which is under 'ipcc' folder.

3.2.3 DKRZ

DKRZ uses two models called ECHAM4/OPYC3 and ECHAM3/LSG. Both the models were developed in co-operation between the Max-Planck-Institute for Meteorology (MPI) and Deutsches Klimarechenzentrum (DKRZ) in Hamburg, Germany. There are four experiments involved in this. They are:

3.2.3.1 Control Integration

In this experiment, simulation is done over several hundred years of length keeping the atmospheric force constant. The IPCC Data Distribution Center (DDC) distributes data of a 240-year period according to the length of the climate change experiments (the greenhouse gas and the greenhouse gas plus sulphate aerosol forcing runs) available from the Max-Planck-Institute. The various components for which the runs are made are:

- **Total surface solar radiation*:*** It is the surface solar radiation. The units are 'W/m**2'.
- **Mean sea level pressure:** Pressure reduced to the mean-sea level. Units are 'Pa'
- **Precipitation:** Total Precipitation rate. Units are 'mm/day'.
- **2-meter temperature*:*** Temperature at 2 meters above the ground. Units are 'K'.
- **2-meter maximum temperature:** Monthly maximum temperature at 2 meter above the ground. Units are 'K'.

- **2-meter minimum temperature:** Monthly minimum temperature at 2 meter above the ground. Units are ‘K’.
- **2-meter dew point temperature**: Temperature at dew point at 2 meter above the ground [K].
- **10-meter wind speed:** Wind speed, at 10 meter above the ground [m/s].

3.2.3.2 Greenhouse Gas Integration

Here the greenhouse gas forcing is increased gradually to represent the observed changes in forcing due to all the greenhouse gases from 1860 to 1990. From 1990 to 2100 it uses an increase in concentrations represented by the IS92a emissions scenario. The various components for which the runs are made are same as the ones in Section 3.2.3.1

3.2.2.3 Greenhouse Gas plus Sulphate Integration (Scenario 1)

The forcing includes not only the greenhouse gas forcing described with the "greenhouse run" but also the direct radioactive effect of historic sulphate aerosol concentrations from 1860 to 1990 and a scenario of sulphate aerosol concentrations from 1990 to 2049 derived from the sulphur emissions in the IS92a scenario. The various components for which the runs are made are the same as the ones in Section 3.2.3.1

3.2.2.4 Greenhouse Gas plus Sulphate Integration (Scenario 2)

The forcing includes not only the greenhouse gas forcing described with the "greenhouse run" but also the direct radiative effect and the indirect cloud effect of historic sulphate aerosol concentrations from 1860 to 1990 and a scenario of sulphate aerosol concentrations from 1990 to 2049. The sulphate aerosol concentrations are calculated in the ECHAM4 model from the sulphur emissions in the IS92a scenario.

Additionally the troposheric ozone has been modified according to IS92a. The various components for which the runs are made are same as the ones in Section 3.2.3.1

3.2.3.5 Grid Definition for ECHAM4/OPYC3

The model resolution used here is abbreviated by the term 'T42' which corresponds to a horizontal resolution of 128*64 grid points. The grid orientation is west to east, north to south. The upper left and right corner, lower left and right corner are shown below

I=1, J=1 (0.00 E, 87.8638 N)	I=128, J=1 (357.1875 E, 87.8638 N)
I=1, J=64 (0.00 E, 87.8638 S)	I=128, J=64 (357.1875 E, 87.8638 S)

3.2.3.6 Grid Definition for ECHAM3/LSG

The model resolution used here is abbreviated by the term 'T21' which corresponds to a horizontal resolution of 64*32 grid points. The grid orientation is west to east, north to south. The upper left and right corner, lower left and right corner are shown below

I=1, J=1 (0.00 E, 85.761 N	I=128, J=1 (354.3750 E, 85.761 N)
I=1, J=64 (0.00 E, 85.761 S)	I=128, J=64 (354.3750 E, 85.761 S)

For purposes of analysis all the data is saved under ‘dkrz1’and ‘dkrz2’, which are under ‘GCMs’, which is under ‘ipcc’ folder.

3.2.4 CCCma

It uses a model called CGCMS1, which was developed by CCCma. There are three experiments in it. They are:

3.2.4.1 Control Integration

The IPCC distributed data of the control run computed is available for the following components:

- **Total surface solar radiation*:*** It is the surface solar radiation. The units are 'W/m**2'
- **Mean sea level pressure:** Pressure reduced to the mean-sea level. Units are 'Pa'
- **Total Precipitation:** Total Precipitation rate. Units are 'mm/day'
- **2-meter temperature*:*** Temperature at 2 meters above the ground. Units are 'K'
- **2-meter maximum temperature:** Monthly maximum temperature at 2 meters above the ground. Units are 'K'
- **2-meter minimum temperature:** Monthly minimum temperature at 2 meters above the ground. Units are 'K'
- **10-meter wind speed:** Wind speed at 10 meters above the ground [m/s].
- **2-meter specific humidity:** Screen Specific humidity 'kg/kg'

3.2.4.2 Greenhouse Gas Integration

The IPCC distributed data of the Greenhouse Gas Integration run computed is same as the ones in Section 3.2.4.1

3.2.4.3 An ensemble of 3 Greenhouse Gas plus Sulphate Integrations (CCGSa1, CCGSa2, CCGSa3)

Ensemble simulation means that a number of runs with identical forcing, but with different initial conditions, are performed. The IPCC distributed data of the 3 Greenhouse Gas plus sulphate Integration runs computed is the same as the ones in Section 3.2.4.1

3.2.4.4 Grid Definition of CGCMS1

The model resolution used here is abbreviated by the term 'T32' which corresponds to a horizontal resolution of 96*48 grid points. The grid orientation is west to east, north to south. The upper left and right corner, lower left and right corner are shown below:

I=1, J=1 (0.00 E, 87.1591 S)	I=96, J=1 (356.2500 E, 87.1591 S)
I=1, J=48 (0.00 E, 87.1591 N)	I=96, J=48 (356.2500 E, 87.1591 N)

3.2.5 GFDL

It uses a model called GFDL-R15. There are three experiments in it. They are:

3.2.5.1 Control Integration

The control integration, in which the atmospheric forcing is kept constant, simulates a period of 1000 years. The IPCC distributed data of the control run computed is available for the following components:

- **Net short wave at the ground:** Net short wave at the ground in 'W/m**2'
- **Surface pressure :** Surface pressure in 'Pa'
- **Total Precipitation:** Total Precipitation in 'mm/day'
- **Temperature :** Lowest level temperature in 'K'
- **Zonal wind :** Lowest level u-wind component in 'm/sec'
- **Meridinal wind :**Lowest level v-wind component in 'm/sec'

3.2.5.2 Greenhouse Gas Integration

The IPCC distributed data of the Greenhouse Gas Integration run computed are the same as the one in Section 3.2.5.1 with an additional component of mixing ratio measured in 'kg/kg'

3.2.5.3 Greenhouse Gas plus Sulphate Integrations

The IPCC distributed data of the Greenhouse Gas Integration run computed are the same as the ones in Section 3.2.5.1 with an additional component of mixing ratio measured in 'kg/kg'

3.2.5.4 Grid Definition of CGCMS1

The model resolution used here is abbreviated by the term 'R15' which corresponds to a horizontal resolution of 48*40 grid points. The grid orientation is west to east, north to south. The upper left and right corner, lower left and right corner are shown below

I=1, J=1 (0.00 E, 86.5980 S)	I=48, J=1 (352.5000 E, 86.5980 S)
I=1, J=40 (0.00 E, 86.5980 N)	I=48, J=40 (352.5000 E, 86.5980 N)

3.2.6 NCAR

It uses a model called NCAR1. There are three experiments in it. They are:

3.2.6.1 Control Integration

The IPCC distributed data of the control run computed is available for the following components:

- **Surface air temperature:** Surface air temperature measured in 'K'
- **Mean Sea Level Pressure:** Mean sea level pressure measured in 'Pa'

- **Total Precipitation:** Total precipitation measured in 'mm/day'
- **Mixing ratio:** Mixing ratio measured in 'kg/kg'
- **Total incident solar radiation:** Total incident solar radiation in 'W/m**2'
- **Zonal wind:** Zonal component of surface wind in 'm/s'
- **Meridinal wind:** Meridinal component of surface wind in 'm/s'
- **Surface Temperature :** Surface temperature in 'K'

3.2.6.2 Greenhouse Gas Integration

The IPCC distributed data of the Greenhouse Gas Integration run computed is available for the components discussed in Section 3.2.6.1

3.2.6.3 Greenhouse Gas plus Sulphate Integrations

The IPCC distributed data of the 3 Greenhouse Gas plus sulphate Integration runs computed is available for the components discussed in Section 3.2.6.1

3.2.6.4 Grid Definition

The model resolution used here is abbreviated by the term 'R15' which corresponds to a horizontal resolution of 48*40 grid points. The grid orientation is west to east, north to south. The upper left and right corner, lower left and right corner are shown below

I=1, J=1 (0.00 E, 86.5980 S)	I=48, J=1 (352.5000 E, 86.5980 S)
I=1, J=40 (0.00 E, 86.5980 N)	I=48, J=40 (352.5000 E, 86.5980 N)

3.2.7 CCSR and NIES

It uses a model called CCSR/NIES; there are three experiments in it. They are:

3.2.7.1 Control Integration

The IPCC distributed data of the control run computed is available for the following components:

- **Temperature:** Temperature in 'K'
- **Mean-sea level Pressure**: Mean sea level pressure in 'Pa'
- **Total Precipitation**: precipitation in 'mm/day'
- **Specific humidity**: specific humidity in 'kg/kg'
- **Surface short wave radiation**: Surface shortwave radiation in 'W/m**2'
- **Magnitude of wind**: Magnitude of wind in 'm/sec'
- **Maximum temperature**: Maximum temperature in 'K'
- **Minimum temperature**: Minimum temperature in 'K'

3.2.7.2 Greenhouse Gas Integration

The IPCC distributed data of the Greenhouse Gas Integration run computed is available for the components explained in Section 3.2.7.1

3.2.7.3 Greenhouse Gas plus Sulphate Integrations

The IPCC distributed data of the 3 Greenhouse Gas plus sulphate Integration runs computed is available for the components explained in Section 3.2.7.1

3.2.7.4 Grid Definition of CGCMS1

The model resolution used here is abbreviated by the term 'T21' which corresponds to a horizontal resolution of 64*32 grid points. The grid orientation is west to east, north to south. The upper left and right corner, lower left and right corner are shown below

I=1, J=1 (0.00 E, 85.7606 N)	I=64, J=1 (357.1875 E, 85.7606 N)
I=1, J=32 (0.00 E, 85.7606 S)	I=64, J=32 (357.1875 E, 85.7606 S)

CHAPTER 4: METHODOLOGY

4.1 Introduction

Based on the results from the United Kingdom Hadley's Climate Model, by the year 2100 temperatures in Louisiana could increase by about 3^0F in spring and summer, slightly less in winter and slightly more in fall.

To visualize the effect of increase, the mean values are increased by a certain percentage on the regional climate and the climate is predicted based on that increase. The mean values of maximum temperature, minimum temperature and precipitation are increased by 5% and 15%, respectively. When mean increases by a certain percentage, the standard deviation changes at the same rate as the mean does, but skewness doesn't change with the increase in the mean. Therefore parameter files are modified accordingly and the weather is generated for those scenarios using CLIGEN model.

The effects of increase in means of the weather components are illustrated with a graphical representation. Comparative graphs are drawn between the climate generated using the original parameter file and the changed parameter file. Figures 4.1 to 4.4 show the graphical representation of yearly and monthly generated data for a 5% and 15 % increase in the average mean respectively. Red dotted lines represent the weather generated using the original parameter file and the green solid line represents the weather generated from the modified parameter file.

As there seems to be a significant change in the future climate, there is a need for the prediction of climate for Louisiana on a finer scale with good precision.

For this purpose a spatial downscaling method is used. As there are several methods for spatial downscaling, based on the availability of data, requirements of analysis and objectives of the current project, an empirical/statistical downscaling technique has been used.

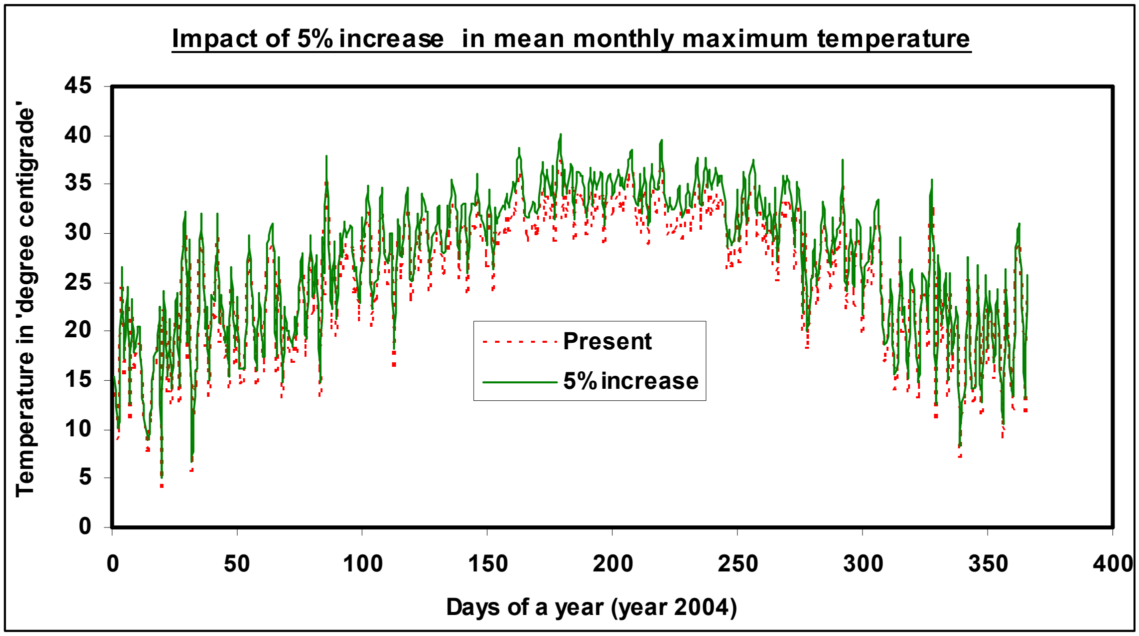

Figure 4.1: Impact of 5% increase in monthly mean maximum temperature (year)

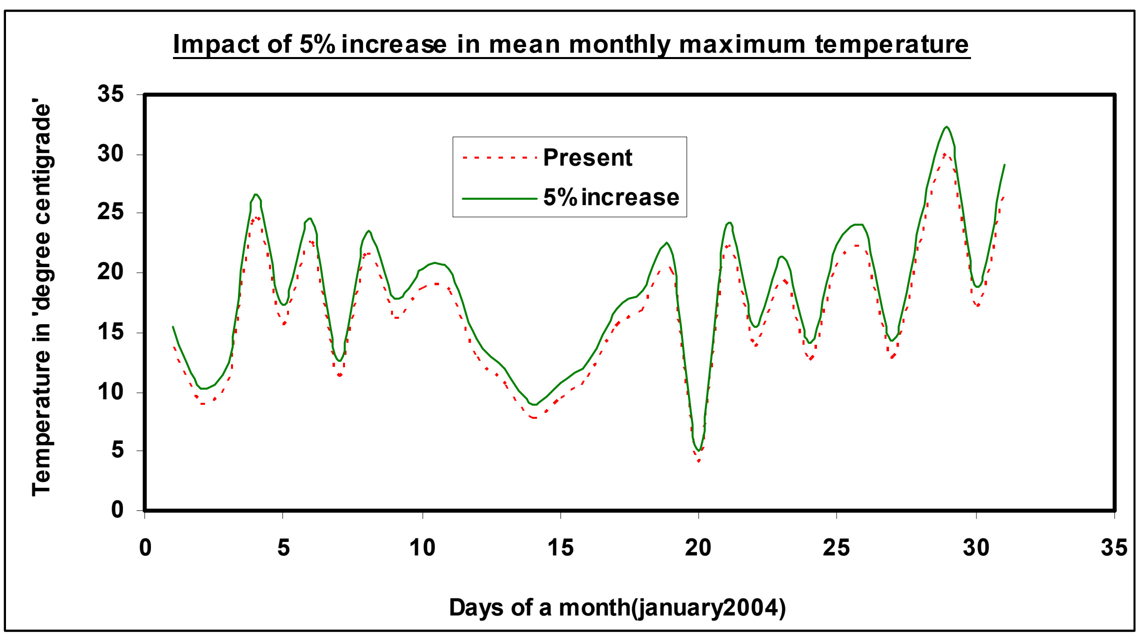

Figure 4.2: Impact of 5% increase in monthly mean maximum temperature (month)

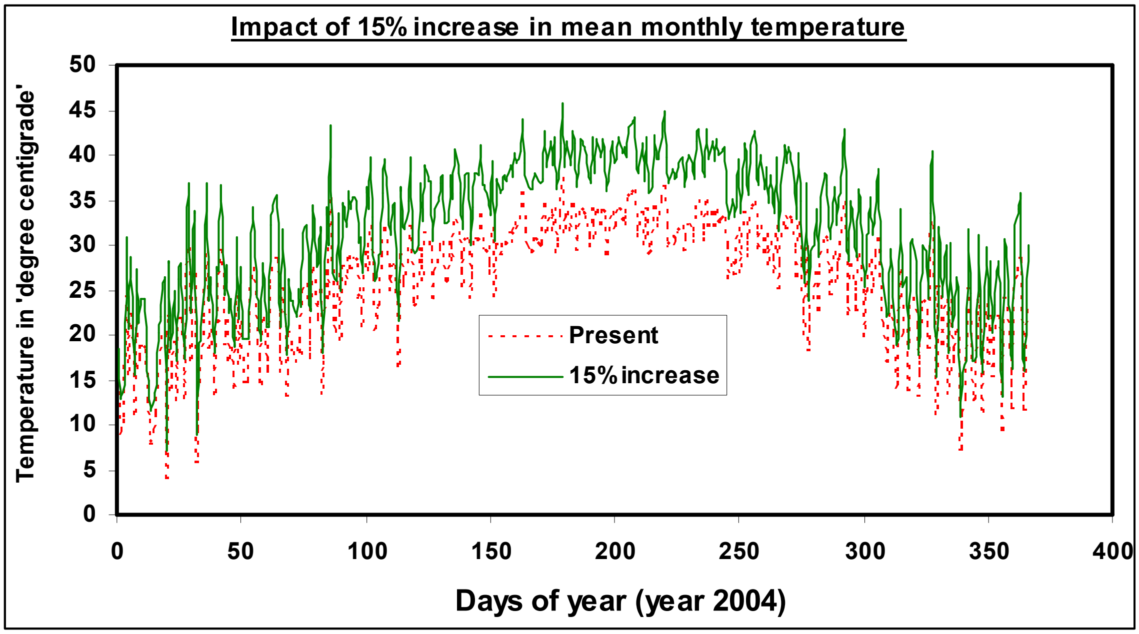

Figure 4.3: Impact of 15% increase in monthly mean maximum temperature (year)

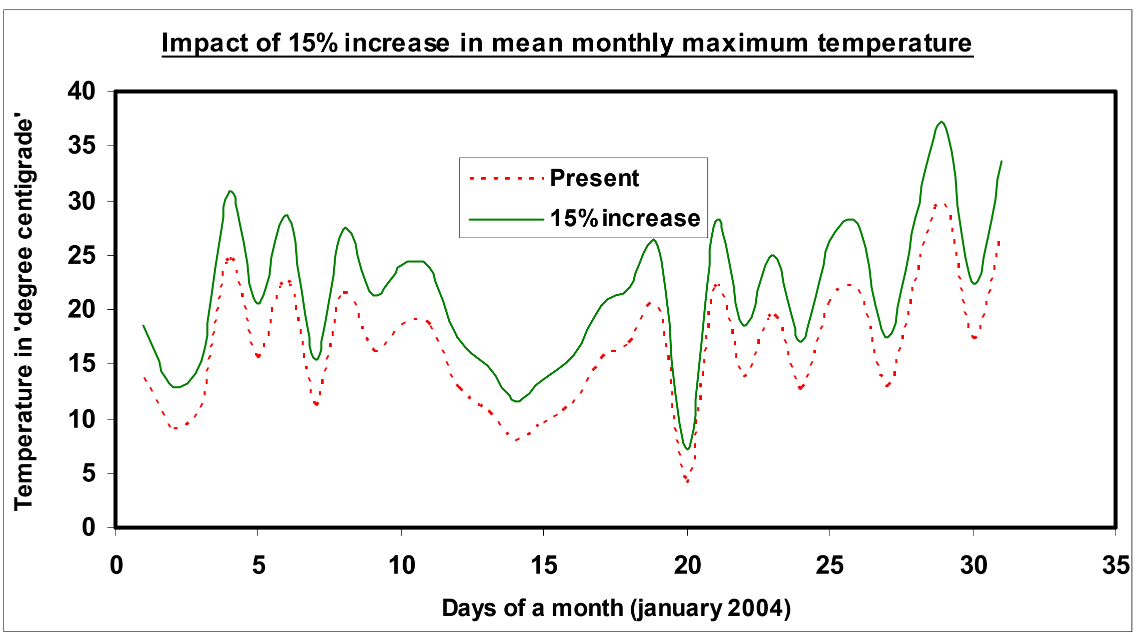

Figure 4.4: Impact of 15% increase in monthly mean maximum temperature (month)

An empirical/statistical downscaling method requires both global and regional model data. There are several steps involved in the collection of data, which is explained in detail in Section 4.2.

4.2 Steps Involved in Data Collection

Since the analysis mainly involves global and regional models, there are several steps involved in the collection of data such as, selection of models, experiments in different models, emission scenarios, etc., which are mainly for the global models and for the regional model important steps are the process of weather generation, computational details of parameters, etc., which are explained in detail in Sections 4.2.1 and 4.2.2.

4.2.1 Data Collection for Global Models

Global climate data was downloaded from Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (DDC), a repository for Global Climate model data output from seven major research centers the data of which are available at **http://ipcc-ddc.cru.uea.ac.uk.** Two types of emission scenarios are available, IS92a, which is the result obtained from GCM runs, based on the IPCC-IS92a or similar emission scenarios and the second one is SRES, which is the result obtained by GCM runs based on the IPCC-SRES scenarios. A step-by-step procedure involved in the selection and downloading process for this project is shown in the form of a flow chart in Figure 4.5

The data downloaded is saved in different folders. The file structure used for saving the data and also for the purpose of analysis is shown in the appendix

4.2.2 Data collection for CLIGEN

For the purpose of regional modeling, data has been downloaded from Climate Generation (CLIGEN) model (**http://horizon.nserl.purdue.edu/CLIGEN).** It consists of parameter files with a “.par” extension, historic data files with a “.dat” extensions, station details, source code, executable files, etc. The formats of the parameter files and the process of weather generation is discussed in detail in Chapter 3.

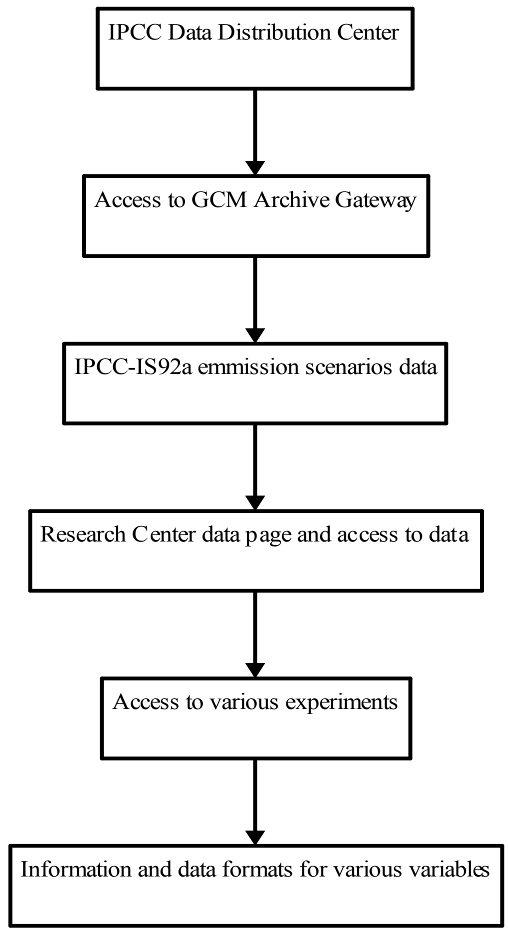

Figure 4.5: Steps involved in accessing required in the process of downloading the data for different weather variables from the IPCC website

4.2.2.1 CLIGEN model Description

Parameter files are developed using the concepts of probability and statistics. CLIGEN generates nine weather variables, which are daily precipitation occurrence, amount, duration, peak storm intensity, time to peak, and daily values of maximum, minimum, and dew point temperatures, solar radiation, and wind speed and direction on a monthly basis.

Parameter values that are used by CLIGEN to generate the daily weather data at a given location which are derived as: Probabilities of precipitation occurrences of a wet day following a wet day and a wet day following a dry day, and mean, standard deviation, and the skew coefficient of daily precipitation of each month are directly taken from the station daily precipitation record. The mean 0.5–h maximum precipitation depths are triangulated with three adjacent stations selected from the CLIGEN database. The time–to–peak parameter is also estimated by triangulation.

A first–order two–state Markov chain is used to generate precipitation occurrence for a day based on whether the previous day was wet or dry. If a random number that is drawn from a uniform distribution for each day is less than the precipitation probability for the given previous day status, a precipitation event is predicted. For a predicted rain day, a skewed normal distribution is used to generate daily precipitation amounts for each month (Nicks and Lane, 1989)

$$x = \frac{6}{g}\left\{\left[\frac{g}{2}\left(\frac{R-\mu}{s}\right)+1\right]^{1/3}-1\right\}+\frac{g}{6} \qquad (4.1)$$

Where

x = the standard normal variate,

R = the daily precipitation amount,

μ = the mean of the daily amounts for the month,

s = the standard deviation of the daily amounts for the month, and

g = the skew coefficient of the daily amounts for the month.

For the other weather variables, such as maximum and minimum temperatures and solar radiation, mean, standard deviation, computational details are explained in Section 2.4 of Chapter 2.

4.3 Mapping of Weather Stations

All available stations in the CLIGEN database for Louisiana are plotted on a Louisiana state map with a one-degree by one-degree latitude-longitude grid on it. It is shown in Figure 4.6. Table 4.1 shows the details of all the weather stations.

For the purpose of analysis, the grid selection has been extended more towards the coastal region. Therefore the area between latitudes 27^0 and 31^0 south to north and between longitudes 95^0W and 87^0W is considered for analysis, making a total of 35 grids.

For all the grids, a representative point, which lies exactly in the center of each grid box, is selected as the representative station for that particular grid; hence there are 35 representative stations. The weather details of all the representative stations are unknown, except for their geographic location.

Figure 4.6 shows the weather stations mapped on a Louisiana map with one degree by one-degree latitude longitude grid. Table 4.1 shows the details of the weather stations. Figure 4.7 shows the central values of each grid with CLIGEN weather stations. The details of central stations, latitude, longitude, and grid number are shown in Table 4.2

4.4 Analysis

An empirical/statistical downscaling spatial downscaling method is used for the analysis. As the main focus is on coastal Louisiana, though the coastal part of Louisiana falls mostly under 10 latitude-longitude grids, considering a grid size of one degree by one degree, the grids are extended to 35 to get more accurate results. The center of each grid cell is taken as a representative station for that particular grid. Therefore we have 35 representative stations. As there is no data available for the representative stations except the latitude and longitude details, Inverse Distance Weighted Interpolation technique is used to get details of the meteorological parameters for the representative stations as explained in Section 4.4.2. The distances of all the 46 weather stations of CLIGEN to all the central values of all the grids is calculated using the Great Circle Distance formula, which is explained in Section 4.4.1.

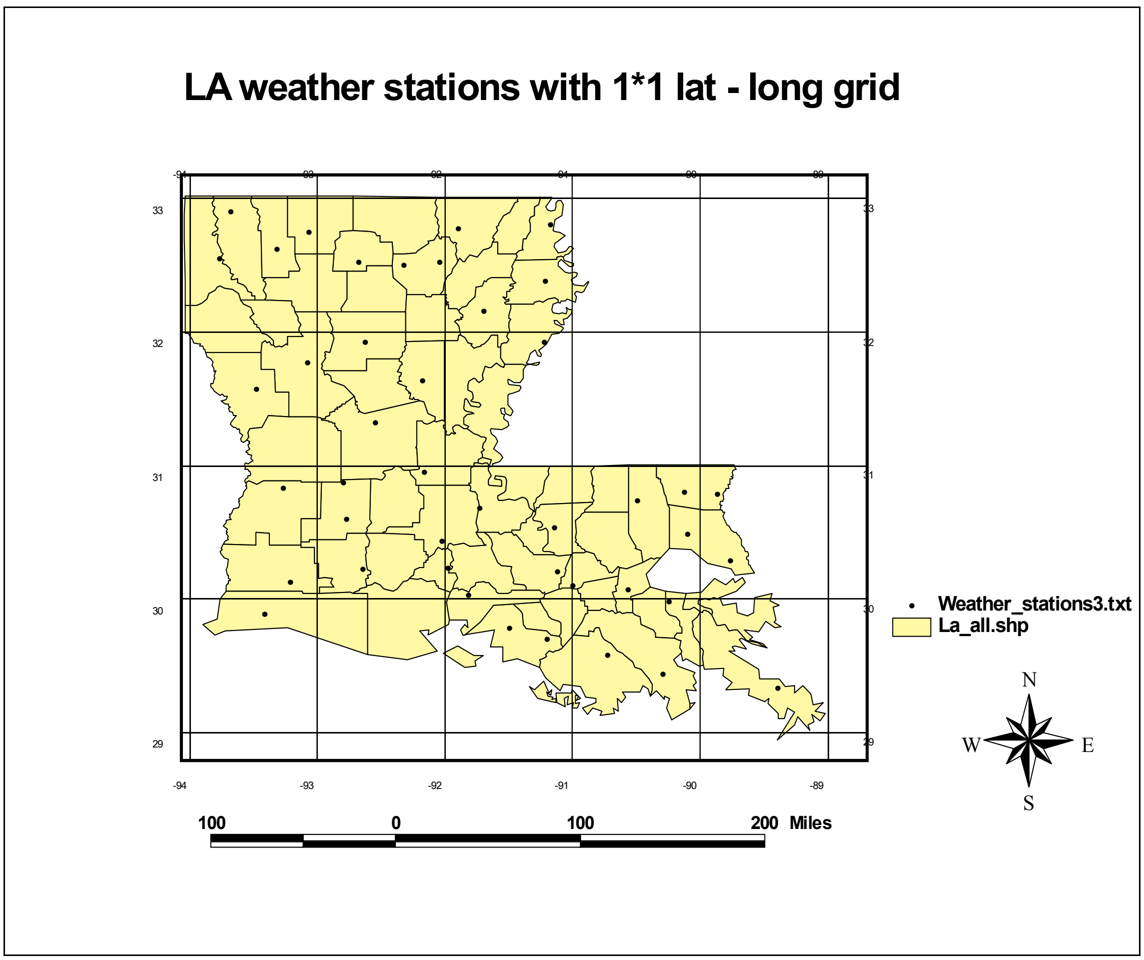

Figure 4.6: Map showing all the weather stations considered in CLIGEN model with one degree by one-degree lat, long grid overlaid on the top. Dots indicate the location of weather stations

Table 4.1: Details of Weather Stations

Station_id	Station_name	Latitude	Longitude
La160098	Alexandria	31.32	-92.55
La160205	Amite	30.73	-90.5
La160537	Bastrop	32.77	-91.9
La160549	Baton rouge wb ap	30.53	-91.15
La160639	Belah fire tower	31.63	-92.18
La160945	Bogalusa	30.78	-89.87
La161157	Boothville	29.33	-89.4
La161287	Bunkie	30.95	-92.17
La161411	Calhoun	32.5	-92.33
La161565	Carville	30.2	-91.12
La162151	Covington	30.48	-90.1
La162367	Deridder	30.83	-93.27
La162534	Donaldson ville	30.1	-91
La162800	Elizabeth	30.87	-92.8
La163313	Franklin la	29.78	-91.5
La163327	Franklin 3 sse	30.8	-90.13
La163433	Galliano	29.43	-90.3
La163800	Grand coteau	30.43	-92.03
La163979	Hackberry	29.88	-93.42
La164034	Hammond	30.53	-90.48
La164355	Homer	32.75	-93.07
La164407	Houma	29.58	-90.73
La164700	Jennings	30.22	-92.65
La165026	Lafayette	30.23	-91.98
La165078	Lake charles	30.12	-93.22
La165090	Lake providence	32.8	-91.18
La165892	Many elec plant	31.57	-93.48
La166117	Melville	30.68	-91.73
La166244	Minden	32.62	-93.32
La166303	Monroe	32.52	-92.05
La166394	Morgan city	29.7	-91.2
La166582	Natchitoches	31.77	-93.08
La166657	New Iberia	30.03	-91.82
La166660	Moisant int ap	29.98	-90.25
La166938	Oberlin fire tower	30.6	-92.78
La167344	Plain dealing	32.9	-93.68
La167767	Reserve la 30.07	30.07	-90.57
La168067	Ruston	32.52	-92.68
La168163	Saint joseph	31.92	-91.23
La168440	Sherveport	32.55	-93.77
La168539	Slidell	30.28	-89.77
La168923	Tallulah	32.38	-91.22
La169319	Vermillon	29.78	-92.2
La169803	Winnfield	31.92	-92.63
La169806	Winnsboro	32.15	-91.7

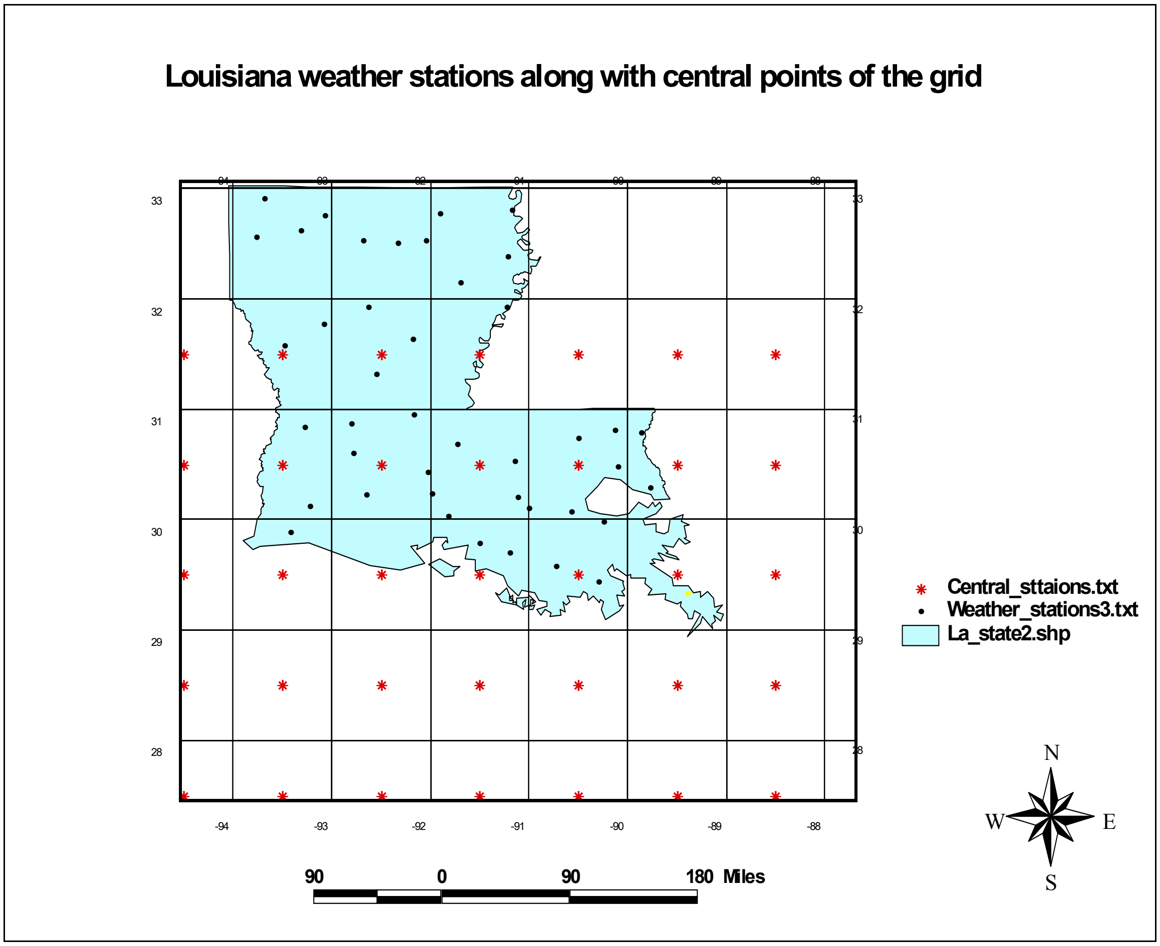

Figure 4.7: Map showing all the weather stations considered in the CLIGEN model and central values of all the required grids with one degree by one-degree lat, long grid overlaid on the top. Dots indicate the location of weather stations. Star symbol indicates central values of all the required grids.

For all the representative stations (center point of each grid), the five nearest stations are selected using great circle distance formula and the meteorological components are obtained using inverse distance interpolation as explained in Sections 4.4.1 and 4.4.2.

4.4.1 Great Circle Distance Formula

The distance between two points on the earth's surface can be calculated by using its latitude and longitude coordinates. Latitude is the angle above or below the equator in degrees, whereas longitude is the angel east or west of the Greenwich meridian.

Table 4.2: Details of central grid points

Grid	Latitude	Longitude
1	27.5	-94.5
2	27.5	-93.5
3	27.5	-92.5
4	27.5	-91.5
5	27.5	-90.5
6	27.5	-89.5
7	27.5	-88.5
8	28.5	-88.5
9	28.5	-89.5
10	28.5	-90.5
11	28.5	-91.5
12	28.5	-92.5
13	28.5	-93.5
14	28.5	-94.5
15	29.5	-94.5
16	29.5	-93.5
17	29.5	-92.5
18	29.5	-91.5
19	29.5	-90.5
20	29.5	-89.5
21	29.5	-88.5
22	30.5	-88.5
23	30.5	-89.5
24	30.5	-90.5
25	30.5	-91.5
26	30.5	-92.5
27	30.5	-93.5
28	30.5	-94.5
29	31.5	-94.5
30	31.5	-93.5
31	31.5	-92.5
32	31.5	-91.5
33	31.5	-90.5
34	31.5	-89.5
35	31.5	-88.5

Therefore the distance between any two latitudes and longitudes in miles is given by the formula:

$$D = 69.1 \times \left(\frac{180}{\pi}\right) \times \arccos[\sin(lat1) \times \sin(lat2) + \cos(lat1) \times \cos(lat2) \times \cos(long1 - long2)]$$

Where

D= the distance in miles between any two latitudes and longitudes

lat1 = the latitude of the first point in degrees

lat2 = the latitude of the second point in degrees

long1 = the longitude of the first point in degrees

long2 = the longitude of the second point in degrees

Distances are calculated for all the central values of the grids to all the weather stations and then for central point of each grid five stations are chosen based on their distances, five closest stations are chosen for each grid.

Hence there are five stations with all known parameters and one station for which only latitude and longitude are known, but all the parameters are unknown. Unknown values are calculated using the Inverse Distance Weighted Interpolation method.

4.4.2 Inverse Distance Weighted Interpolation

This is one of the common methods for interpolating scatter points. Inverse distance weighted methods are based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points. The interpolating surface is a weighted average of the scatter points and the weight assigned to each scatter point diminishes as the distance from the interpolation point to the scatter point increases.

There are several methods available for inverse distance weighted interpolation. The method that is used in this particular case is Shepard's Method.

4.4.2.1 Shepard's Method

The simplest form of inverse distance weighted interpolation is sometimes called "Shepard's method". The equation used is as follows:

$$F(x, y) = \sum_{i=1}^{n} w_i f_i \tag{4.4}$$

Where n is the number of scatter points in the set, f_i are the prescribed function values at the scatter points (e.g., the data set values), and w_i are the weight functions assigned to each scatter point. The classical form of the weight function is:

$$W_i = \frac{h_i^{-p}}{\sum_{j=1}^{n} h_j^{-p}} \tag{4.5}$$

Where p is an arbitrary positive real number called the power parameter (typically, p=2) and h_i is the distance from the scatter point to the interpolation point

$$y_i = \sqrt{(x - x_i) + (y - y_i)^2} \tag{4.6}$$

Where (x, y) are the coordinates of the interpolation point and (x_i, yi) are the coordinates of each scatter point. The weight function varies from a value of unity at the scatter point to a value approaching zero as the distance from the scatter point increases. The weight functions are normalized so that the weights sum to unity. The effect of the weight function is that the surface interpolates each scatter point and is influenced most strongly between scatter points by the points closest to the point being interpolated.

For the current analysis the above method is used to interpolate CLIGEN parameters to get the CLIGEN parameter file for all the central stations (unknowns). For all these 35 stations 30-year and 100-year weather is generated using the CLIGEN model.

A 30-year data is generated from 1961-1990, which is considered as a base scenario and a 100-year data is generated to compare the warming trend. To justify the process of interpolation, this statistical analysis is carried out for the 30 year runs. Using the Statistical Analysis System (SAS) software correlation analysis is made for 13 grids, which mostly cover the land area and which have stations with known data near to them.

4.5 Correlation analyses for base files

Correlation analysis is performed to check how well the generated data is correlated for interpolated stations. For this purpose stations are considered, for which all the details are known. Assuming that it is an unknown point, distances are calculated using the great circle distance formula, as explained in Section 4.5.1 and four closest stations are considered and using an inverse distance interpolation technique interpolations are performed and parameter files are generated and 30-year daily weather sequence is generated using CLIGEN. A correlation analysis is performed between the original and the interpolated data. These results are shown in Table 4.3.

Table 4.3 shows the correlation coefficients for precipitation, maximum temperature, minimum temperature and solar radiation for the grids 16,17,18,19,20,23,24,25,26,27,30,31 and 32.

Temperature values and solar radiation values are well correlated but precipitation values are not well correlated.

4.6 Application of spatial downscaling technique

Spatial downscaling technique generally refers to a method in which sub-grid changes in climate are calculated as a function of large scale climate (Section 2.3). The basic assumption made for the purpose of this analysis is that statistical relationships which are calculated using the observed data will also remain valid under future conditions.

Table 4.3: Details of grids for which correlation analysis is performed and correlation results for temperature, maximum temperature, minimum temperature and solar radiation

Grid	Precipitation	Maximum Temperature	Minimum Temperature	Solar Radiation
16	0.26901	0.99927	0.99021	0.98971
17	0.23194	0.99949	0.99581	0.99109
18	0.27960	0.99952	0.99861	0.99999
19	0.25970	0.99886	0.99640	0.99995
20	0.27691	0.99816	0.97781	0.99979
23	0.25395	0.99886	0.99788	0.99923
24	0.28015	0.99955	0.99909	0.99984
25	0.24460	0.99952	0.99903	0.99880
26	0.25726	0.99978	0.99883	0.99940
27	0.25250	0.99945	0.99839	0.99964
30	0.29877	0.99950	0.99802	0.99911
31	0.28800	0.99990	0.99874	0.99934
32	0.26500	0.99955	0.99760	0.99343

For the entire grid points (1 to 35) CLIGEN parameter files are generated using the interpolation technique, which is explained in Sections 4.5.2 and 4.5.2.1. The format of the obtained parameter file is same as the CLIGEN input file shown in Figure 3.1

Most of the global models predict climate on hourly and daily bases until the year 2099 on a very coarse resolution. Monthly means are calculated from the available daily data from the global models. The units of the monthly means obtained from global models and CLIGEN are different from the units used in CLIGEN model. Therefore the units of Global monthly means are converted according to the units of CLIGEN.

GCM data files are generally in ‘grib’format, therefore they are read using ‘pingo’ software. The downloaded GCM data is divided into two files based on base(1961-1990) and warm (1991-2090) scenarios. Using a computer program code mean values of the daily data for both scenarios is calculated and saved in ASCII format, with an '.asc' extension. The format of an '.asc' file is shown in appendix C

Once the monthly means are obtained, a fortran90 program was written, which reads the parameter files of all the grids and replaces the means with the global means, standard deviation and skewness values are then changed accordingly (if mean increases by a certain percentage standard deviation increases by the same percentage but skewness remains the same). Assuming that the probabilities remain the same, probabilities of a wet day followed by a wet day and a wet day followed by a dry day remain the same. The Fortran code used to perform the above operation is shown in the appendix D.

Weather is generated for the obtained parameter files for 1961-1990(base scenario) and for 1991-2099 (warming trend). Comparative graphs are plotted for the base runs for CLIGEN and the three experiments performed by the Canadian model (CCCma) for the base scenario and also as the analysis is done for two global models (CCCma and CSIRO), comparisons are made between the two models and are represented in graphical form.

Correlation analysis is performed for CLIGEN and the three experiments of the Canadian model (CCCma) for precipitation, maximum temperature, minimum temperature and solar radiation for the grid points 24, 25 and 26 and also between the two global models (CCCma and CSIRO) for grid 24 (latitude 30.5^0 and longitude 90.5^0). The results obtained are shown in Chapter 5.

CHAPTER 5: RESULTS AND CONCLUSIONS

The analysis was undertaken for two global climate models, viz, the Canadian (CCCma) and the Australian model (CSIRO). The results are mainly based on:

1. The correlation analysis of the generated outputs of the basic CLIGEN (unchanged parameter files) model and the three experiments of CCCma (CLIGEN modified parameter files using the averages from CCCma model): Control integration (ci), Green house gas integration (ggi) and green house gas plus sulphate integration (ggsi).
2. Correlation analysis of the generated outputs of all the three experiments (ci, ggi, ggsi) of CCCma and CSIRO for the grid point 24 (latitude 30.5^0 and longitude 90.5^0).
3. Time series plots of the generated output of the basic CLIGEN, CCCma and CSIRO for both base(1961-1990) and warm (1991-2090) scenarios for the four basic important weather variables: precipitation (prcp), maximum temperature (tmax), minimum temperature (tmin) and solar radiation (solrad), for all the three experiments(ci, ggi, ggsi) of CCCma and CSIRO.
4. Time series plots of the generated outputs of CCCma and CSIRO for both base (1961-1990) and warm (1991-2090) scenarios for the four basic important weather variables: precipitation (prcp), maximum temperature (tmax), minimum temperature (tmin) and solar radiation (solrad), for all the three experiments (ci, ggi, ggsi) of CCCma and CSIRO.

Using CLIGEN, climate is predicted for the years 1961-1990 (base scenario) and 1991-2090 (warm scenario). Time series graphs are drawn for the warming trends for

CLIGEN and all the three experiments of Canadian model for the predicted precipitation, maximum temperature, minimum temperature and solar radiation data. Correlation analysis is also done for the same weather variables for the grids 24, 25 and 26.

Figures 5.1 to 5.16 are the time series plots. For plotting purpose, two representative years are taken for base and warm scenarios. For the base scenario the year 1975 is considered as a representative year and for the warm scenario the year 2050 is considered as a representative year. Correlation analysis is performed for the whole data for both the scenarios.

5.1 Correlation Analyses for Base Files

Table 5.5 shows the results obtained by performing the correlation analysis using the SAS software. This analysis is mainly performed to check the validity of the interpolated values. Correlations are performed for temperatures, precipitation and solar radiation, the results of which are shown in Table 5.5. Maximum temperature, minimum temperature and solar radiation values are well correlated but precipitation values are not so well correlated. This may be because CLIGEN generates all the parameters independent of each other.

5.2 Climate Prediction Using Spatial Downscaling Method

As discussed earlier in Section 4.8, parameter files are generated for all the grids using CLIGEN and global models. Results are discussed for the climate generated by both the Canadian and the Australian models.

Comparisons are made between the basic CLIGEN parameter files and the parameter files generated using the global model, for all the three experiments (control integration (ci), green house gas integration (ggi), green house gas plus sulphate aerosol integration (ggsi)) for the four basic weather variables, precipitation, maximum temperature, minimum temperature and solar radiation.

Mean precipitation values are under-predicted by the CCCma model by an average of approximately 0.35cm when compared to the values predicted from the basic CLIGEN model. This may be because of the large spatial variation for the global models.

The maximum value of precipitation from the Figure 5.1 for the year 2050 is 147.5 millimeters, which is obtained by running the basic CLIGEN model for the warming period, whereas the value obtained from the control run of the CCCma for precipitation for the year 2050 is 20.7 millimeters. Correlation analyses is performed considering all the predicted years that is 1961-1990 for the base scenario and 1991-2090 for the warming scenario. Correlation coefficient value for basic CLIGEN and the three experiments (control integration, green house gas integration, and green house gas plus sulphate integration) of CCCma for precipitation on an average is 0.9 approximately. The results of the correlation analyses is tabulated in Tables 5.1 to 5.12 for the three grid points (24, 25 and 26)

Temperatures are over-predicted by an average value of approximately 5-6 degree centigrade, but the overall correlation coefficient from the correlation analyses results tabulated in Tables 5.1 to 5.12 shows that the correlation coefficients varies from 0.83-0.99 for all the weather variables, which shows the data predicted using the Canadian model and the data predicted using the basic CLIGEN model is very close. But by the visual observation of the predicted output data and the graphical representation for the years 1975 (for base scenario) and 2050 (for warm scenario) showed in Figures 5.2 and 5.6 shows that the daily temperatures differ. The maximum daily temperature value from the output of the CLIGEN model for the year 2050 is 38.6 degree centigrade whereas the maximum daily maximum temperature value predicted using the CCCma model for the green house gas integration is 47.5 degree centigrade for the year 2050.

According to the IPCC 2001a report global average surface air temperature is projected to increase by 1.4 to 5.8^{0}C over the period of 1990-2100, and the predicted average values for temperature falls in that range.

In case of the minimum temperatures plotted in the Figures 5.3 (warm scenario) and 5.7 (base scenario), highest minimum temperature value for the year 2050 is 34.8 degree centigrade predicted by CCCma for the green house gas integration and the highest minimum temperature value predicted by CLIGEN for the year 2050 is 29.8 degree centigrade, which is the same for control integration of CCCma.

In case of solar radiation for both the base and warm trends, from the Figures 5.4 and 5.8, it is observed that the solar radiation values always follow a specific trend that is the solar radiation value increases from January till June and decreases gradually till December. The maximum value of solar radiation for the year 2050 is 802 Langley obtained from the results of CCCma for green house gas plus sulphate integration and the highest value in case of green house gas integration is 789 Langley, the highest value for Control integration is 789 Langley. The highest value obtained from the output predicted by the CLIGEN is 769 Langley.

Graphs are also plotted for the Australian model and are shown in Figures 5.9 to 5.16. Figure 5.16 shows the warming trends for the year 2050 for the precipitation component. The maximum precipitation value predicted is 82.1 millimeters, which is predicted by the CLIGEN model; whereas the maximum value predicted by the

Australian model is 40.9 millimeters, which is same for both green house gas integration and green house gas plus sulphate integration. Therefore it is concluded that the precipitation values are under predicted by the CSIRO model.

For maximum temperatures, Figures 5.10 and 5.14 shows the graphs plotted for the warming trend and base scenarios respectively. Unlike the CCCma model, maximum temperatures are more from the outputs of basic CLIGEN model. The maximum value is 40 degree centigrade, predicted by the CLIGEN model and the maximum value of CSIRO output is 37.8 degree centigrade obtained from the output of CSIRO green house gas integration experiment.

For minimum temperatures, plotted in Figures 5.11 and 5.15 (warm and base scenarios respectively), the highest minimum temperature value is 35.9 degree centigrade, predicted by the CSIRO green house gas integration and the maximum value predicted by CLIGEN model is 28.9 degree centigrade.

For solar radiation, plotted in Figures 5.12 and 5.15 (warm and base scenarios respectively), the maximum value is 754 Langley, obtained from the predicted output of CLIGEN, and the maximum value obtained from the output of CSIRO is 711 Langley from the green house gas and sulphate integration.

5.3 Correlation Analyses Results and Time Series Plots

The correlation analyses results for all the four weather variables are tabulated in tales 5.1 to 5.12.

Table 5.1: Results of correlation analysis of precipitation for grid 24

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.94614	0.94016	0.92875
cccma_ci	0.94614	1.00000	0.98898	0.98924
cccma_ggi	0.94016	0.98898	1.00000	0.99255
cccma_ggsi	0.92875	0.98924	0.99255	1.00000

Table 5.2: Results of correlation analysis of solar radiation for grid 24

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.96502	0.96502	0.96052
cccma_ci	0.96502	1.00000	0.99675	0.99757
cccma_ggi	0.96282	0.99675	1.00000	0.99707
cccma_ggsi	0.96052	0.99757	0.99707	1.00000

Table 5.3: Results of correlation analysis of maximum temperature for grid 24

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.98465	0.98476	0.98601
cccma_ci	0.98465	1.00000	0.99967	0.99930
cccma_ggi	0.98476	0.99967	1.00000	0.99914
cccma_ggsi	0.98601	0.99930	0.99914	1.00000

Table 5.4: Results of correlation analysis of minimum temperature for grid 24

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.97981	0.97869	0.97965
cccma_ci	0.97981	1.00000	0.99842	0.99902
cccma_ggi	0.97869	0.99842	1.00000	0.99885
cccma_ggsi	0.97965	0.99902	0.99885	1.00000

Table 5.5: Results of correlation analysis of precipitation for grid 25

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.94380	0.95319	0.94406
cccma_ci	0.94380	1.00000	0.98515	0.98943
cccma_ggi	0.95319	0.98515	1.00000	0.98752
cccma_ggsi	0.94406	0.98943	0.98752	1.00000

Table 5.6: Results of correlation analysis of solar radiation for grid 25

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.96760	0.97029	0.96705
cccma_ci	0.96760	1.00000	0.99693	0.99840
cccma_ggi	0.97029	0.99693	1.00000	0.99823
cccma_ggsi	0.96705	0.99840	0.99823	1.00000

Table 5.7: Results of correlation analysis of maximum temperature for grid 25

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.91799	0.91772	0.91499
cccma_ci	0.91799	1.00000	0.99917	0.99941
cccma_ggi	0.91772	0.99917	1.00000	0.99925
cccma_ggsi	0.91499	0.99941	0.99925	1.00000

Table 5.8: Results of correlation analysis of minimum temperature for grid 25

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.84378	0.84480	0.84403
cccma_ci	0.84378	1.00000	0.99940	0.99910
cccma_ggi	0.84480	0.99940	1.00000	0.99919
cccma_ggsi	0.84403	0.99910	0.99919	1.00000

Table 5.9: Results of correlation analysis of solar radiation for grid 26

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.94380	0.95319	0.94406
cccma_ci	0.94380	1.00000	0.98515	0.98943
cccma_ggi	0.95319	0.98515	1.00000	0.98752
cccma_ggsi	0.94406	0.98943	0.98752	1.00000

Table 5.10: Results of correlation analysis of solar radiation for grid 26

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.96760	0.97029	0.96705
cccma_ci	0.96760	1.00000	0.99693	0.99840
cccma_ggi	0.97029	0.99693	1.00000	0.99823
cccma_ggsi	0.96705	0.99840	0.99823	1.00000

Table 5.11: Results of correlation analysis of maximum temperature for grid 26

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.91799	0.91772	0.91499
cccma_ci	0.91799	1.00000	0.99917	0.99941
cccma_ggi	0.91772	0.99917	1.00000	0.99925
cccma_ggsi	0.91499	0.99941	0.99925	1.00000

Table 5.12: Results of correlation analysis of minimum temperature for grid 26

	CLIGEN	cccma_ci	cccma_ggi	cccma_ggsi
CLIGEN	1.00000	0.84378	0.84480	0.84403
cccma_ci	0.84378	1.00000	0.99940	0.99910
cccma_ggi	0.84480	0.99940	1.00000	0.99919
cccma_ggsi	0.84403	0.99910	0.99919	1.00000

Climate prediction is done by making use of the two models: the Canadian model (CCCma) and the Australian model (CSIRO). Comparative graphs are plotted for the two models for all three cases (control integration, green house gas integration and green house gas plus sulphate integration) for both the scenarios (base and warm scenario). Correlation analyses are carried out for all the cases taking 24th grid as the representative grid. Time series graphs are plotted for all the cases and are shown in figures 5.17 to5.36.

Correlation coefficients for all the cases range from 0.80-1.00. Tables 5.13 to 5.36 shows the results tabulated for the correlation analyses.

Table 5.13: Correlation analysis of precipitation for the base scenario of control integration

	cccma_ci_prcp	csiro_ci_prcp
cccma_ci_prcp	1.00000	0.92493
csiro_ci_prcp	0.92493	1.00000

Table 5.14: Correlation analysis of precipitation for the base scenario of green house gas integration

	cccma_ggi_prcp	csiro_ggi_prcp
cccma_ggi_prcp	1.00000	0.98440
Csiro_ggi_prcp	0.98440	1.00000

Table 5.15: Correlation analysis of precipitation for the base scenario of green house gas and sulphate integration

	cccma_ggsi_prcp	csiro_ggsi_prcp
cccma_ci_prcp	1.00000	0.98890
csiro_ci_prcp	0.98890	1.00000

Table 5.16: Correlation analysis of maximum temperature for the base scenario of control integration

	cccma_ci_tmax	csiro_ci_tmax
cccma_ci_tmax	1.00000	0.97212
csiro_ci_tmax	0.97212	1.00000

Table 5.17: Correlation analysis of maximum temperature for the base scenario of green house gas integration

	cccma_ggi_tmax	csiro_ggi_tmax
cccma_ggi_tmax	1.00000	0.90435
Csiro_ggi_tmax	0.90435	1.00000

Table 5.18: Correlation analysis of maximum temperature for the base scenario of green house gas plus sulphate integration

	cccma_ggsi_tmax	csiro_ggsi_tmax
cccma_ggsi_tmax	1.00000	0.98598
Csiro_ggsi_tmax	0.98598	1.00000

Table 5.19: Correlation analysis of minimum temperature for the base scenario of control integration

	cccma_ci_tmin	csiro_ci_tmin
cccma_ci_tmin	1.00000	0.98415
csiro_ci_tmin	0.98415	1.00000

Table 5.20: Correlation analysis of minimum temperature for the base scenario of green house gas integration

	cccma_ggi_tmin	csiro_ggi_tmin
cccma_ggi_tmin	1.00000	0.96037
Csiro_ggi_tmin	0.96037	1.00000

Table 5.21: Correlation analysis of minimum temperature for the base scenario of green house gas and sulphate integration

	cccma_ggsi_tmin	csiro_ggsi_tmin
cccma_ggsi_tmin	1.00000	0.93551
Csiro_ggsi_tmin	0.93551	1.00000

Table 5.22: Correlation analysis of solar radiation for the base scenario of control integration

	cccma_ci_solrad	csiro_ci_solrad
cccma_ci_solrad	1.00000	0.98384
csiro_ci_solrad	0.98384	1.00000

Table 5.23: Correlation analysis of solar radiation for the base scenario of green house gas integration

	cccma_ggi_solrad	csiro_ggi_solrad
cccma_ci_prcp	1.00000	0.98752
csiro_ci_prcp	0.98752	1.00000

Table 5.24: Correlation analysis of solar radiation for the base scenario of green house gas and sulphate integration

	cccma_ggsi_solrad	csiro_ggsi_solrad
cccma_ggsi_solrad	1.00000	0.97120
Csiro_ggsi_solrad	0.97120	1.00000

Table 5.25: Correlation analysis of precipitation for the warming scenario of control integration

	cccma_ci_prcp	csiro_ci_prcp
cccma_ci_prcp	1.00000	0.92995
csiro_ci_prcp	0.92995	1.00000

Table 5.26: Correlation analysis of precipitation for the warming scenario of green house gas integration

	cccma_ggi_prcp	csiro_ggi_prcp
cccma_ggi_prcp	1.00000	0.80899
csiro_ggi_prcp	0.80899	1.00000

Table 5.27: Correlation analysis of precipitation for the warming scenario of green house gas plus sulphate integration

	cccma_ggsi_prcp	csiro_ggsi_prcp
cccma_ggsi_prcp	1.00000	0.88390
csiro_ggsi_prcp	0.88390	1.00000

Table 5.28: Correlation analysis of maximum temperature for the warming scenario of control integration

	cccma_ci_tmax	csiro_ci_tmax
cccma_ci_tmax	1.00000	0.98274
csiro_ci_tmax	0.98274	1.00000

Table 5.29: Correlation analysis of maximum temperature for the warming scenario of green house gas integration

	cccma_ggi_tmax	csiro_ggi_tmax
cccma_ggi_tmax	1.00000	0.95442
csiro_ggi_tmax	0.95442	1.00000

Table 5.30: Correlation analysis of maximum temperature for the warming scenario of green house gas plus sulphate integration

	cccma_ggsi_tmax	csiro_ggsi_tmax
cccma_ggsi_tmax	1.00000	0.96849
csiro_ggsi_tmax	0.96849	1.00000

Table 5.31: Correlation analysis of minimum temperature for the warming scenario of control integration

	cccma_ci_tmin	csiro_ci_tmin
cccma_ci_tmin	1.00000	0.98725
csiro_ci_tmin	0.98725	1.00000

Table 5.32: Correlation analysis of minimum temperature for the warming scenario of green house gas integration

	cccma_ggi_tmin	csiro_ggi_tmin
cccma_ggi_tmin	1.00000	0.99010
csiro_ggi_tmin	0.99010	1.00000

Table 5.33: Correlation analysis of minimum temperature for the warming scenario of green house gas plus sulphate integration

	cccma_ggsi_tmin	csiro_ggsi_tmin
cccma_ggsi_tmin	1.00000	0.98845
csiro_ggsi_tmin	0.98845	1.00000

Table 5.34: Correlation analysis of solar radiation for the warming scenario of control integration

	cccma_ci_solrad	csiro_ci_solrad
cccma_ci_solrad	1.00000	0.97096
csiro_ci_solrad	0.97096	1.00000

Table 5.35: Correlation analysis of solar radiation for the warming scenario of green house gas integration

	cccma_ggi_solrad	csiro_ggi_solrad
cccma_ggi_solrad	1.00000	0.95291
csiro_ggi_solrad	0.95291	1.00000

Table 5.36: Correlation analysis of solar radiation for the warming scenario of green house gas plus sulphate integration

	cccma_ggsi_solrad	csiro_ggsi_solrad
cccma_ggsi_solrad	1.00000	0.96245
csiro_ggsi_solrad	0.96445	1.00000

Tables 5.25 to 5.36 show the correlations of all the warm scenarios. Except for two cases all others are correlated by more than 90%. Tables 5.26 and 5.27 show the two cases in which the correlation coefficient value is less than 0.9. Both the cases are results obtained for the precipitation for the warming scenario for green house gas integration and green house gas plus sulphate integration. But for the same case incase of control integration the values are correlated above 90%, which can be seen in the table 5.25. in case of maximum temperature the correlation coefficient value of green house gas integration value (0.95442) is less than the other two (ci, ggsi). Incase of minimum temperature control integration value (0.98725) is less when compared to the other two (ggi, ggsi). In case of solar radiation green house gas integration value (0.95291) is less when compared to the other two integrations.

Tables 5.13 to 5.24 show the correlations of all the base scenarios for all the three experiments (ci, ggi, ggsi). All the base scenarios are correlated by more than 90%.

When compared between the three experiments (ci, ggi, ggsi) of base scenario, for precipitation, control integration values (0.92493) are less correlated when compared to the other two integrations (ggi, ggsi).

Incase of the maximum temperature green house gas integration values (0.90435) are less correlated when compared to the other two integrations (ci, ggsi).

Incase of minimum temperature green house gas plus sulphate integration values (0.93551) are less correlated when compared with the other two integrations (ggi, ggsi).

Incase of solar radiation green house gas plus sulphate integration values integration values (0.97120) are less correlated when compared to the other two integrations (ci, ggi).

Graphs are plotted for the maximum values of temperature, precipitation and solar radiation of all the years from 1991-2090. Figures 5.41 to 5.49 represent the same.

5.4 Conclusions

- The average maximum value of Precipitation for 100 years (1991-2090) from control integration of CCCma is 27.368 millimeters.
- The average maximum value of Precipitation for 100 years (1991-2090) from green house gas integration of CCCma is 22.442 millimeters.
- The average maximum value of Precipitation for 100 years (1991-2090) from green house gas plus sulphate integration of CCCma is 24.11 millimeters.
- The average maximum value of maximum temperatures for 100 years (1991-2090) from control integration of CCCma is 37.273 degree centigrade.
- The average maximum value of maximum temperature for 100 years (1991-2090) from green house gas integration of CCCma is 45.309 degree centigrade.
- The average maximum value of maximum temperature for 100 years (1991-2090) from green house gas plus sulphate integration of CCCma is 41.594 degree centigrade.
- The average maximum value of solar radiation for 100 years (1991-2090) from control integration of CCCma is 781.24 langley.
- The average maximum value of solar radiation for 100 years (1991-2090) from green house gas integration of CCCma is 780.76 langley.

- The average maximum value of solar radiation for 100 years (1991-2090) from green house gas plus sulphate integration of CCCma is 781.9 langley.
- The average maximum value of Precipitation for 100 years (1991-2090) from control integration of CSIRO is 35.26 millimeters.
- The average maximum value of Precipitation for 100 years (1991-2090) from green house gas integration of CSIRO is 37.915 millimeters.
- The average maximum value of Precipitation for 100 years (1991-2090) from green house gas plus sulphate integration of CSIRO is 37.437 millimeters.
- The average maximum value of maximum temperature for 100 years (1991-2090) from control integration of CSIRO is 36.117 degree centigrade.
- The average maximum value of maximum temperature for 100 years (1991-2090) from green house gas integration of CSIRO is 38.769 degree centigrade.
- The average maximum value of maximum temperature for 100 years (1991-2090) from green house gas plus sulphate integration of CSIRO is 38.381 degree centigrade.
- The average maximum value of solar radiation for 100 years (1991-2090) from control integration of CSIRO is 724.75 langley.
- The average maximum value of solar radiation for 100 years (1991-2090) from green house gas integration of CSIRO is 727.26 langley.
- The average maximum value of solar radiation for 100 years (1991-2090) from green house gas plus sulphate integration of CSIRO is 731.03 langley.

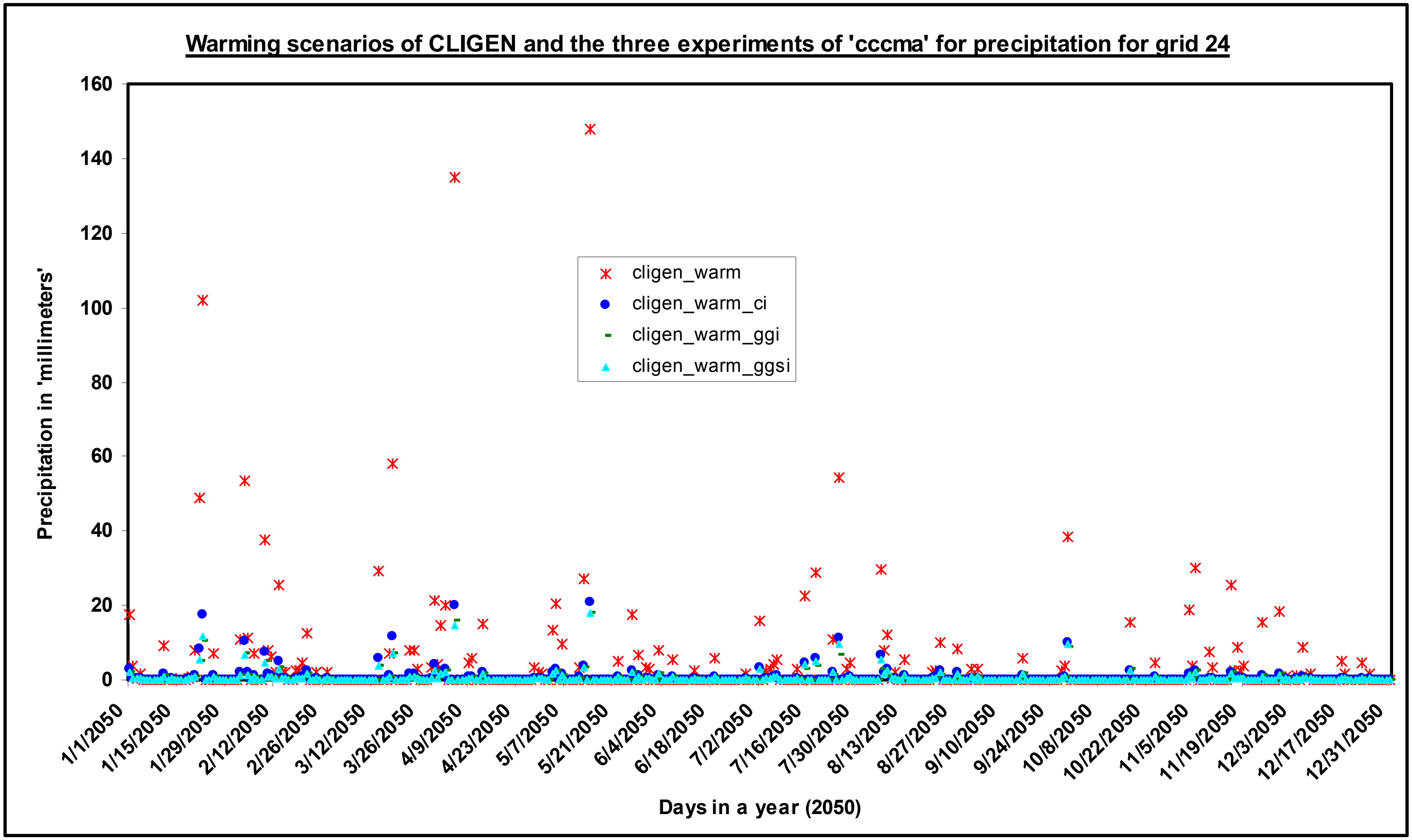

Figure 5.1: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'cccma' for precipitation for the grid 24

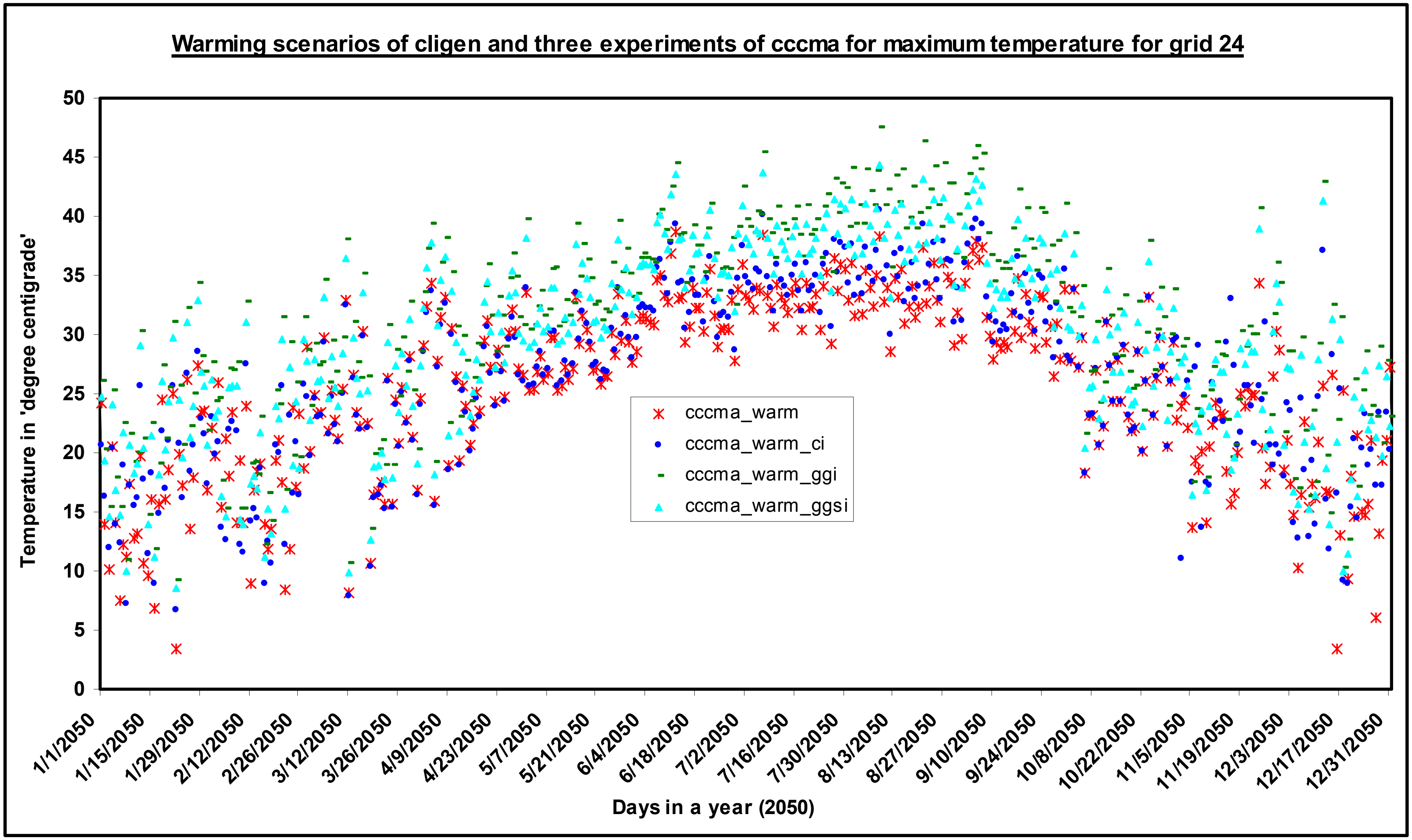

Figure 5.2: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'cccma' for maximum temperature for the grid 24

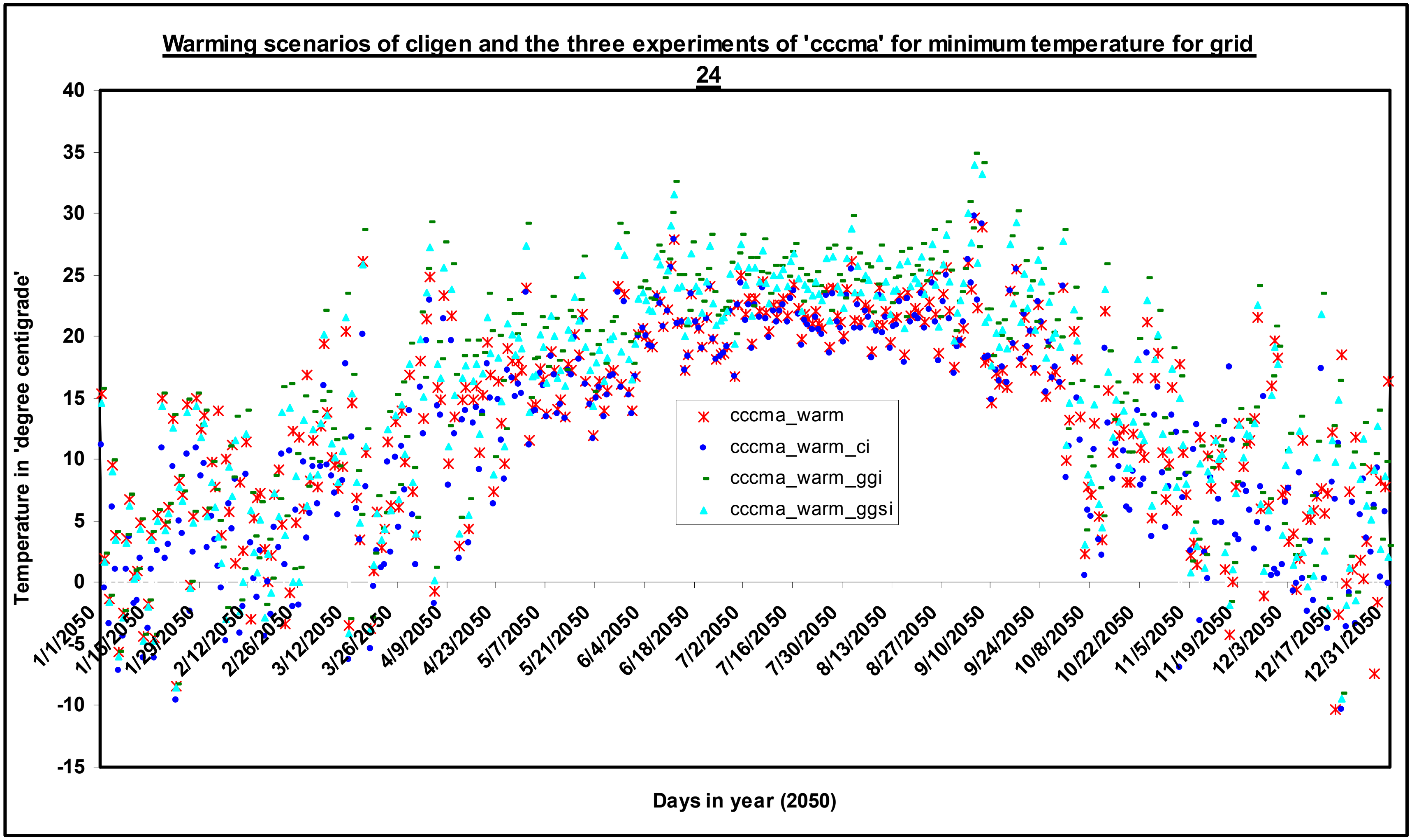

Figure 5.3: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'cccma' for minimum temperature for the grid 24

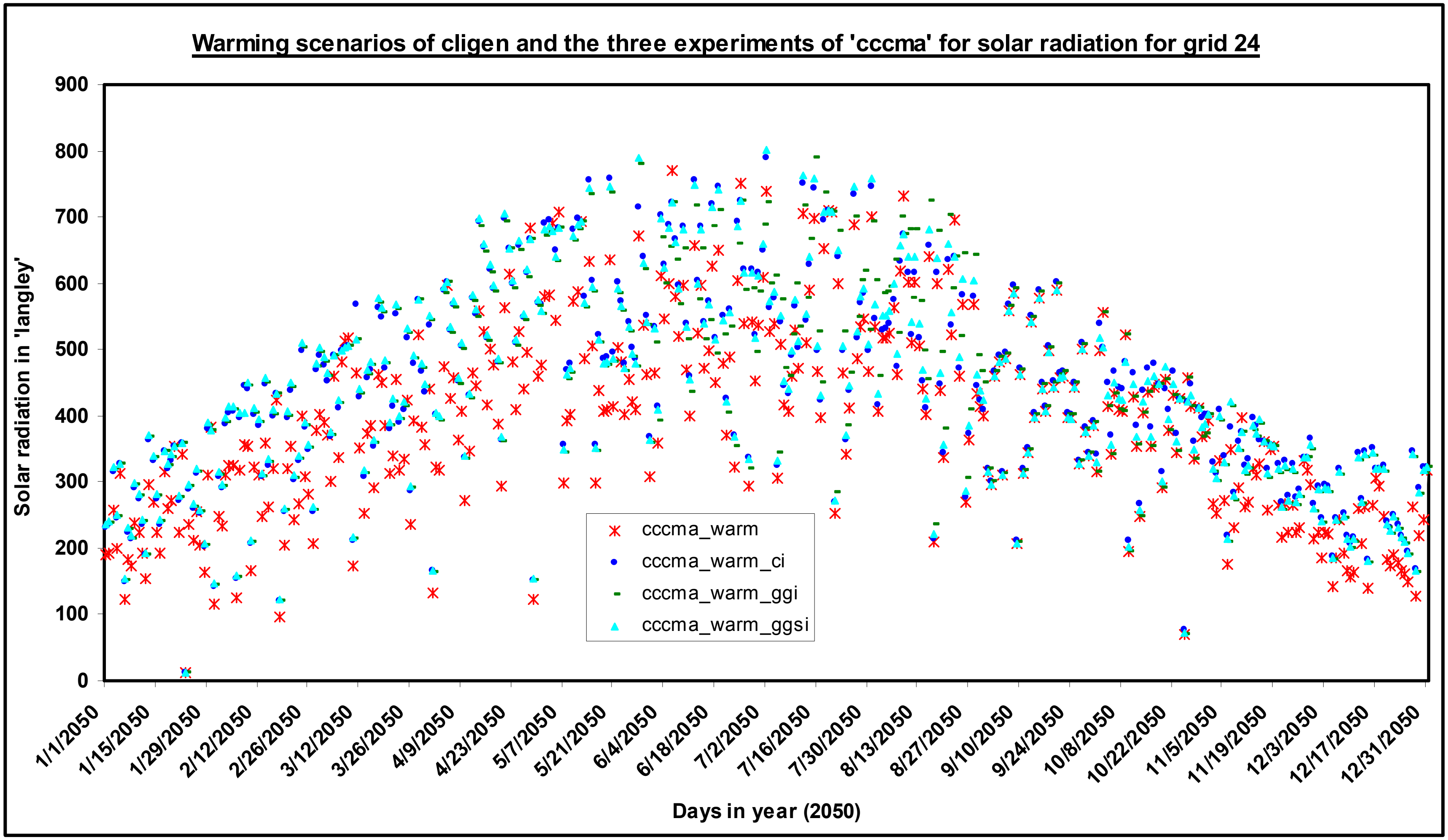

Figure 5.4: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'cccma' for solar radiation for the grid 24

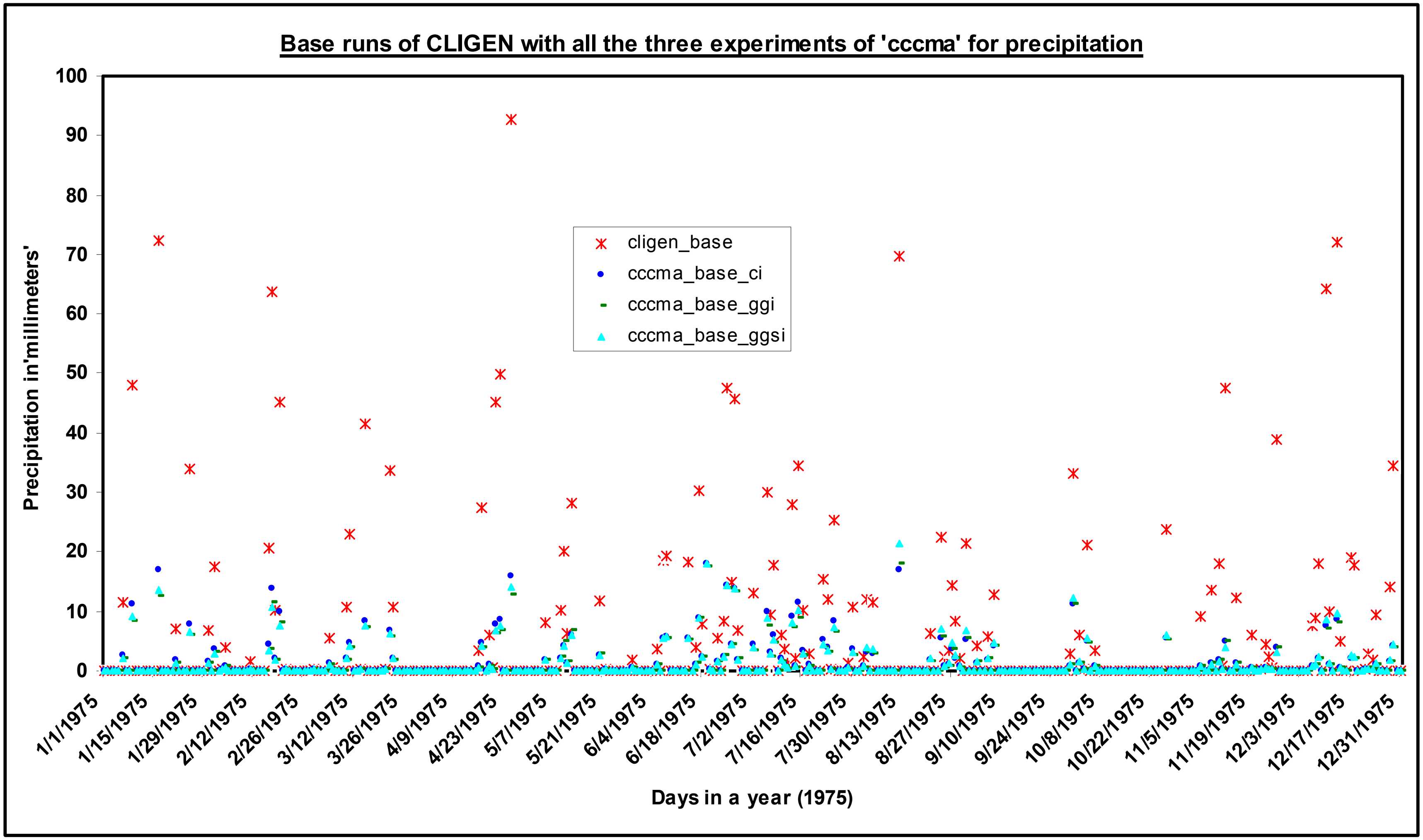

Figure 5.5: Graph showing the base runs of CLIGEN with all the three experiments of 'cccma' for precipitation for grid 24

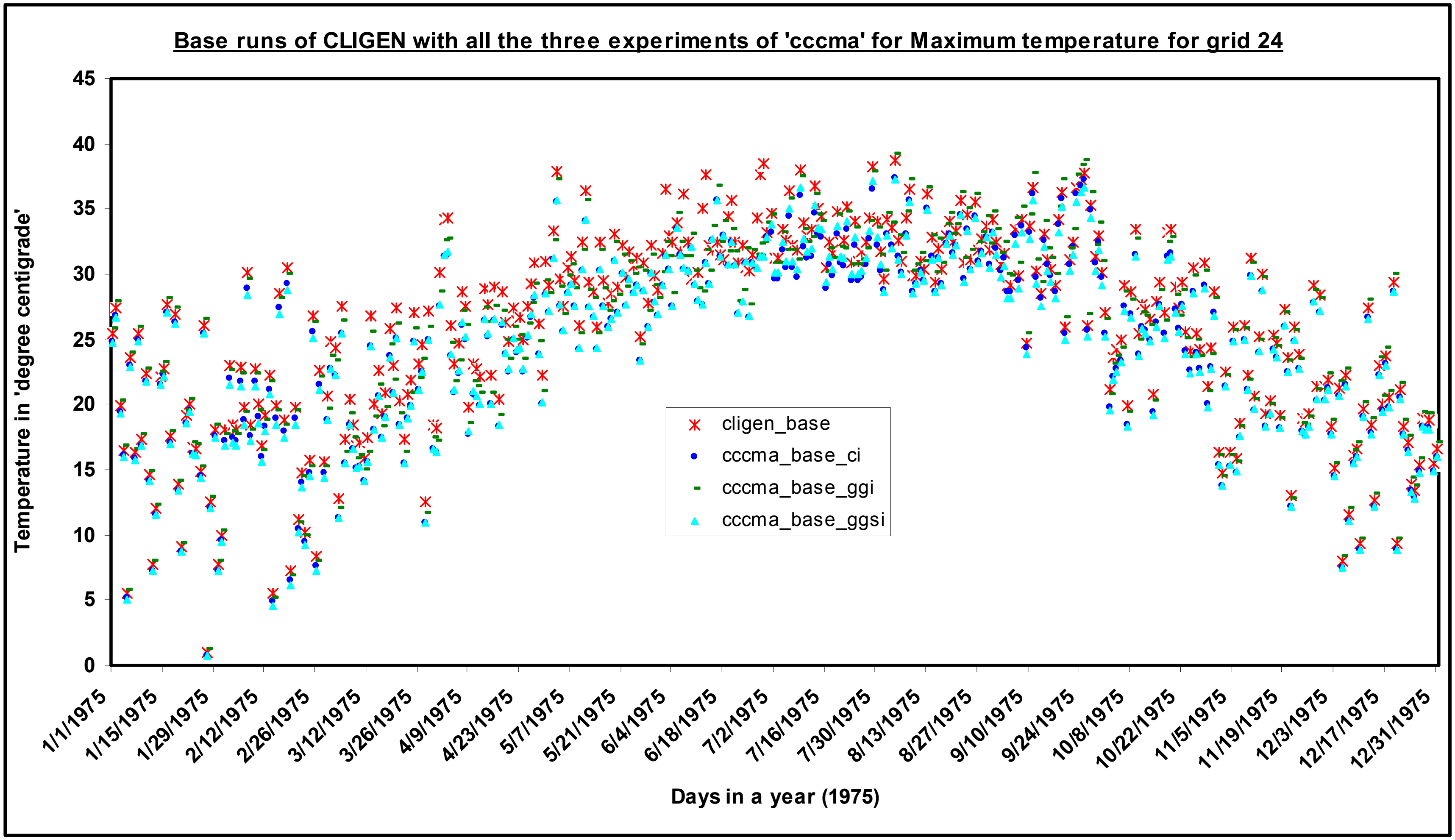

Figure 5.6: Graph showing the base runs of CLIGEN with all the three experiments of 'cccma' for maximum temperature for grid 24

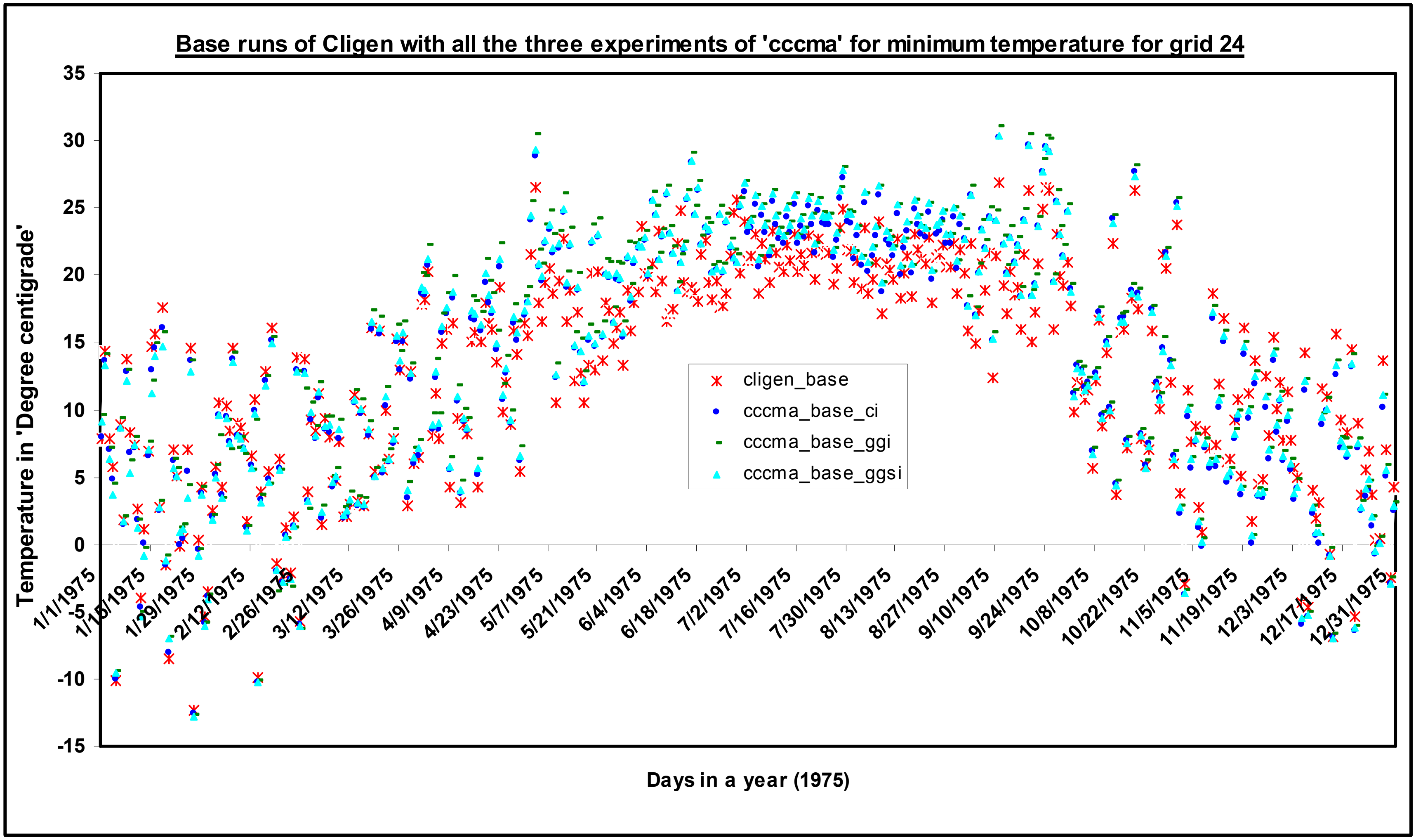

Figure 5.7: Graph showing the base runs of CLIGEN with all the three experiments of 'cccma' for minimum temperature for grid 24

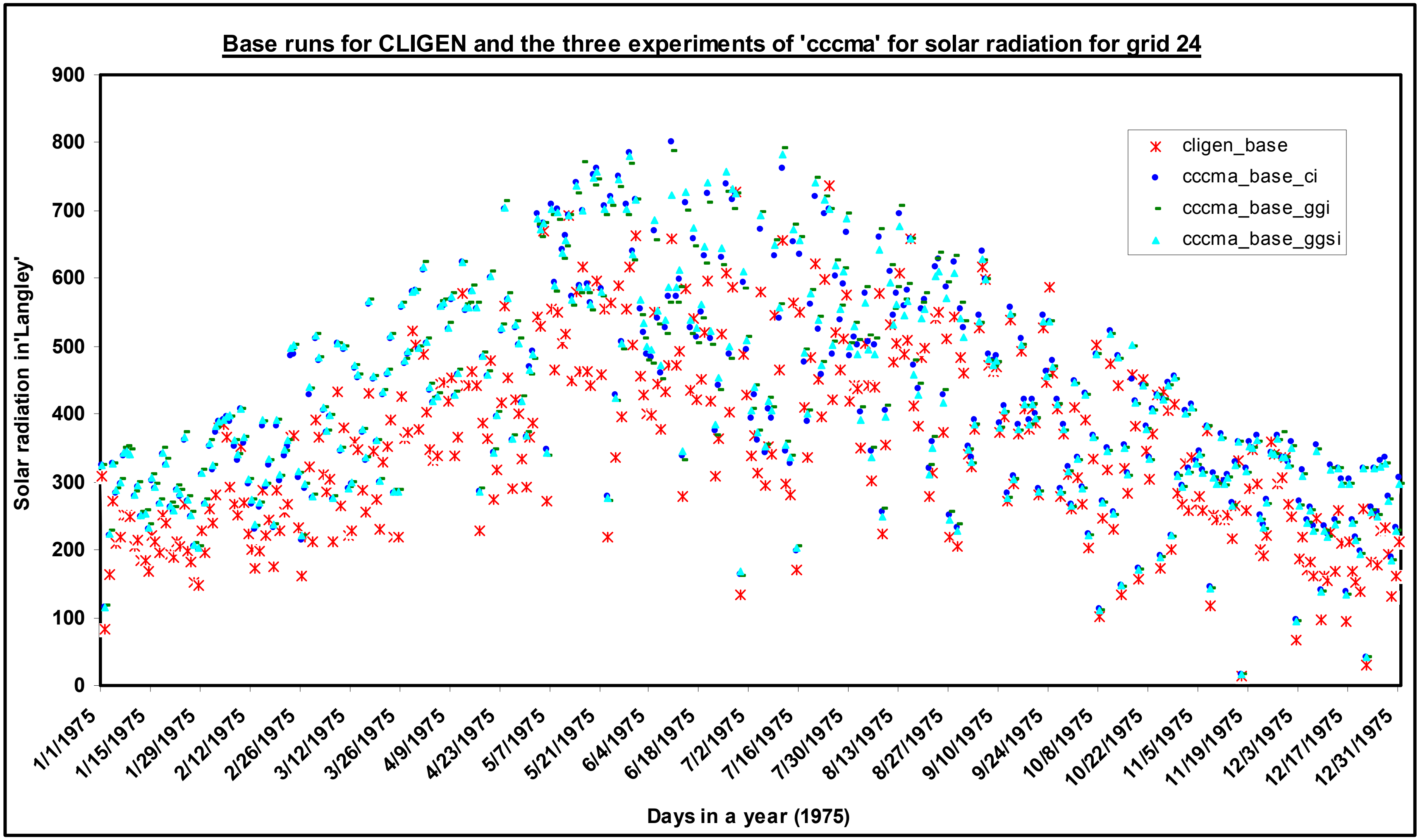

Figure 5.8: Graph showing the base runs of CLIGEN with all the three experiments of 'cccma' for solar radiation for grid 24

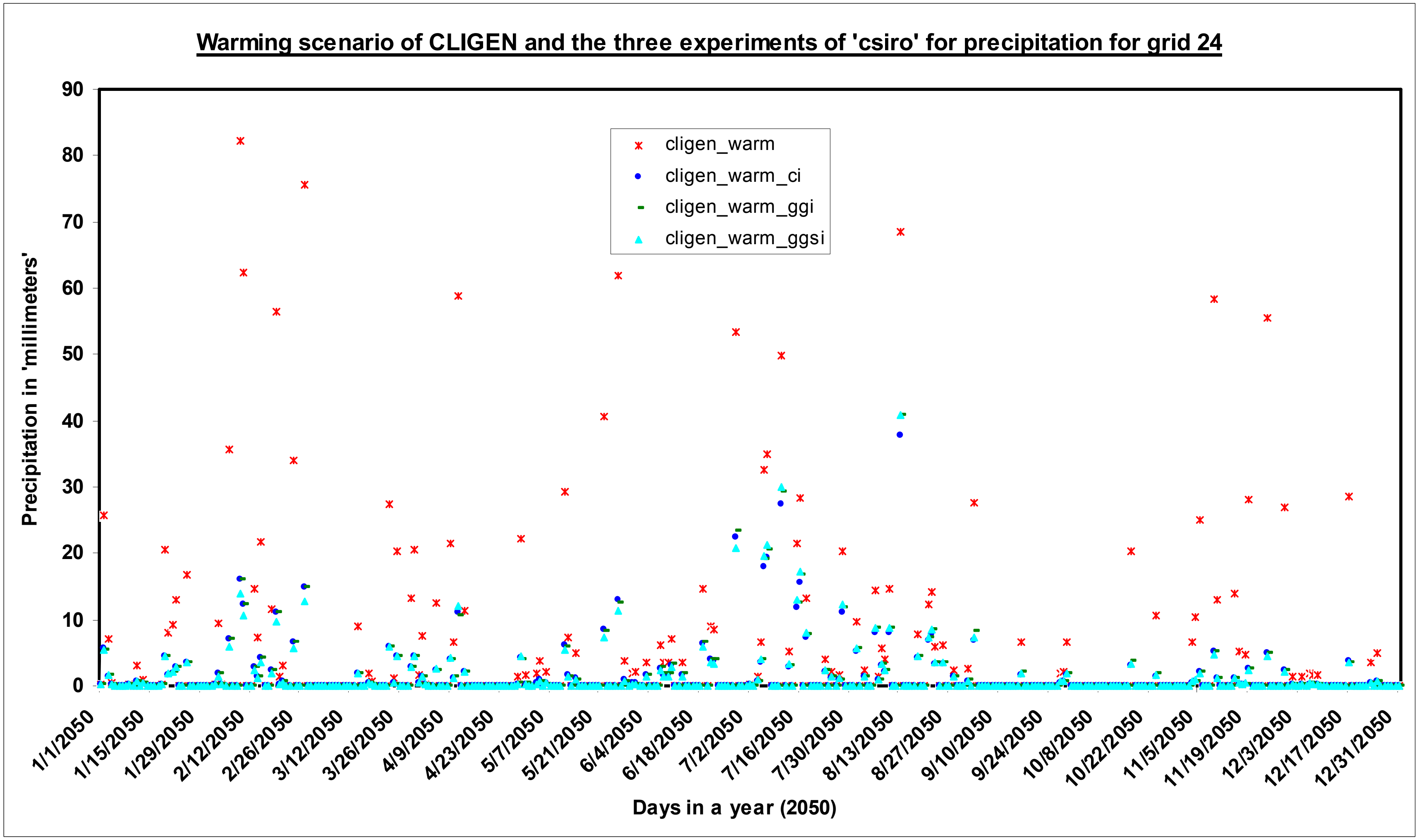

Figure 5.9: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'CSIRO' for precipitation for the grid 24 (latitude 30.5, longitude 90.5)

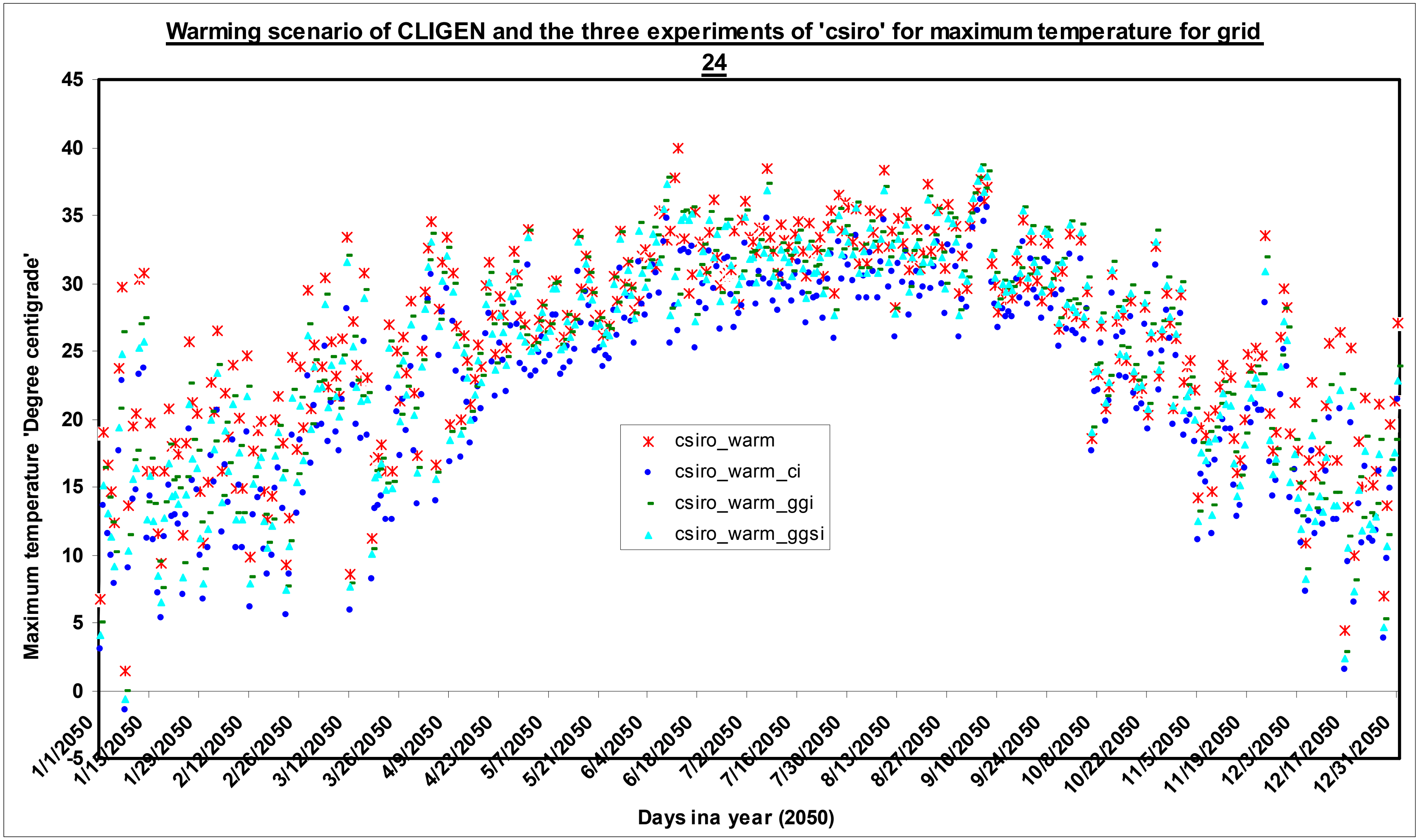

Figure 5.10: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'CSIRO' for maximum temperature for the grid 24 (latitude 30.5, longitude 90.5)

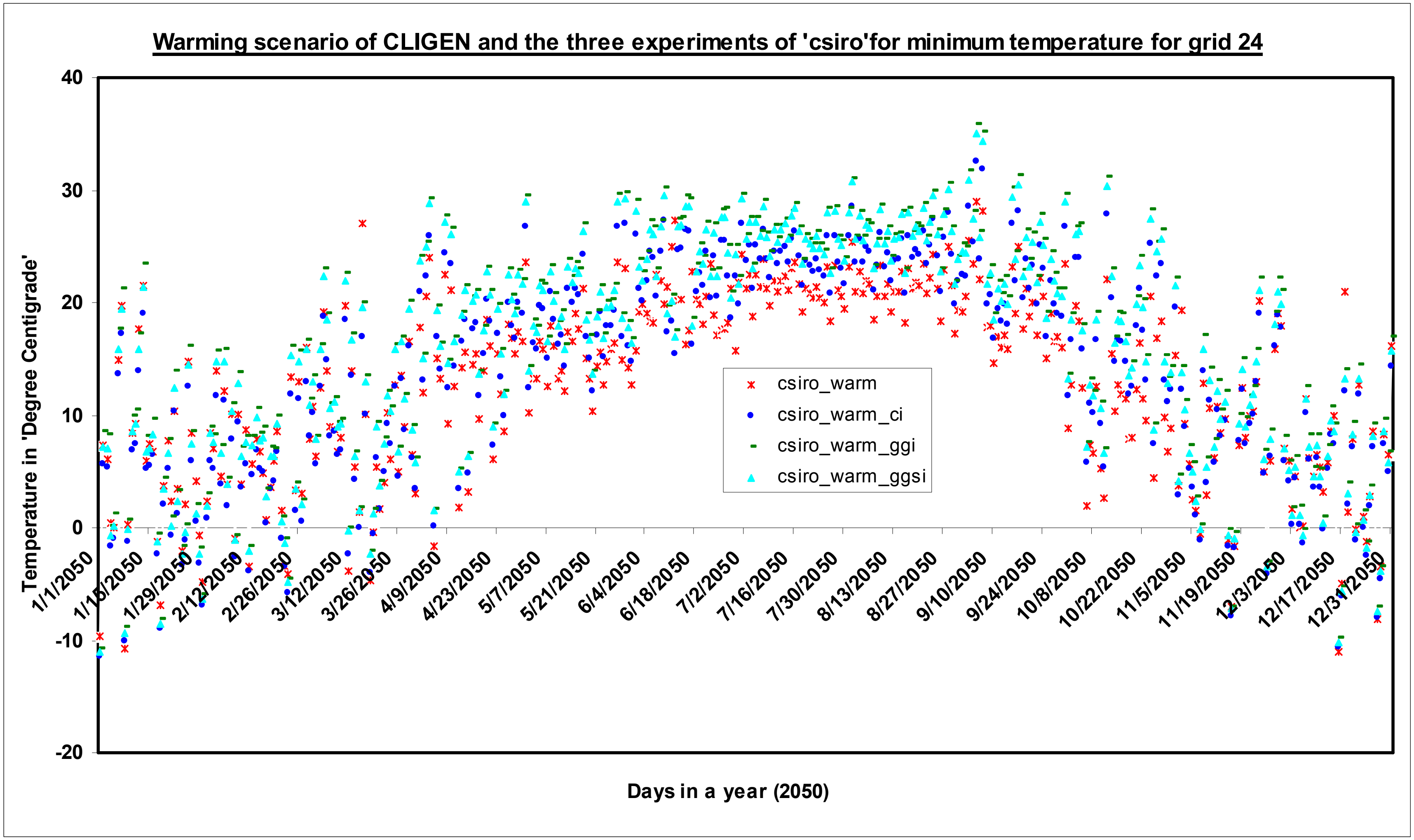

Figure 5.11: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'CSIRO' for minimum temperature for the grid 24 (latitude 30.5, longitude 90.5)

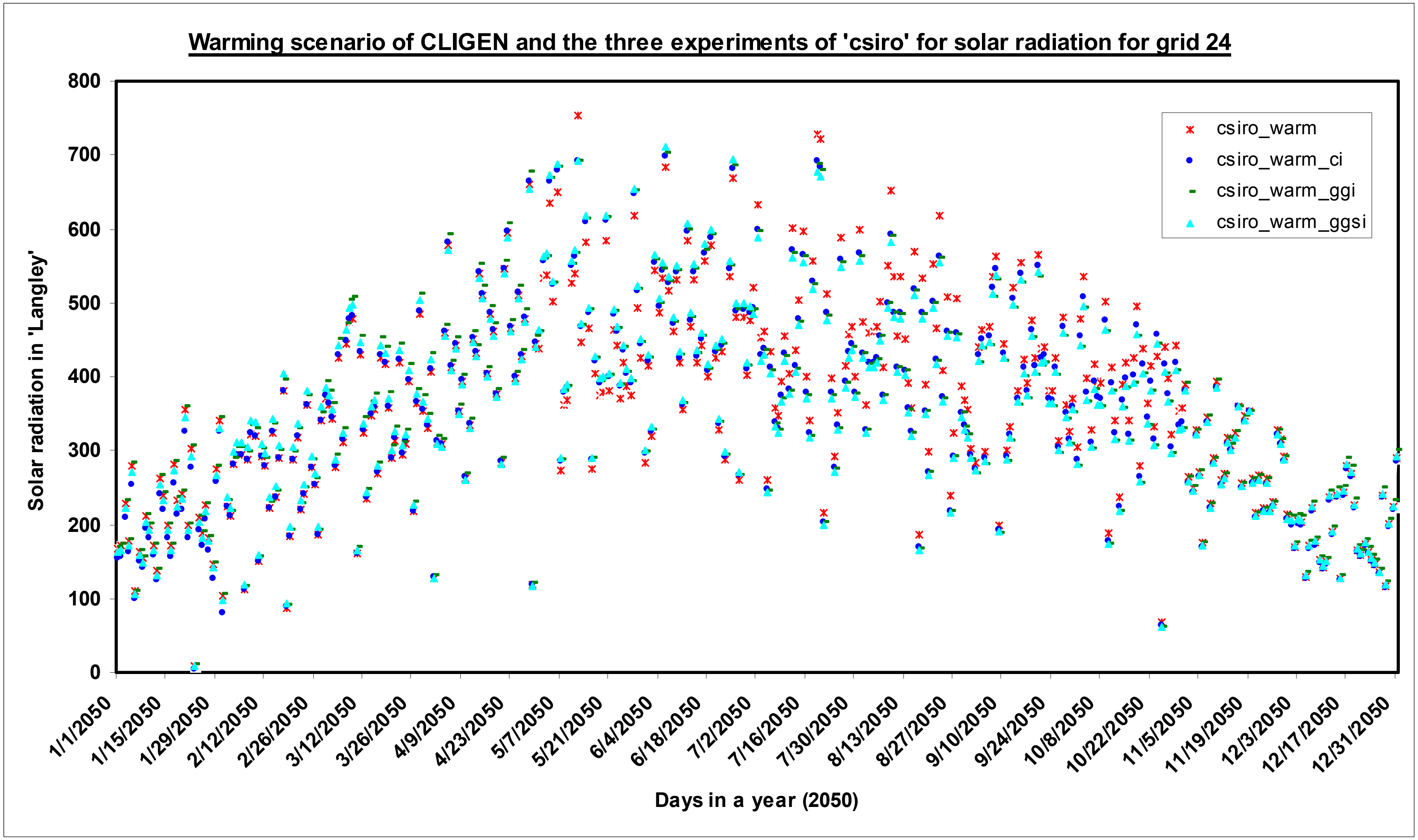

Figure 5.12: Graph showing the warming scenarios of CLIGEN with all the three experiments of 'CSIRO' for solar radiation for the grid 24 (latitude 30.5, longitude 90.5)

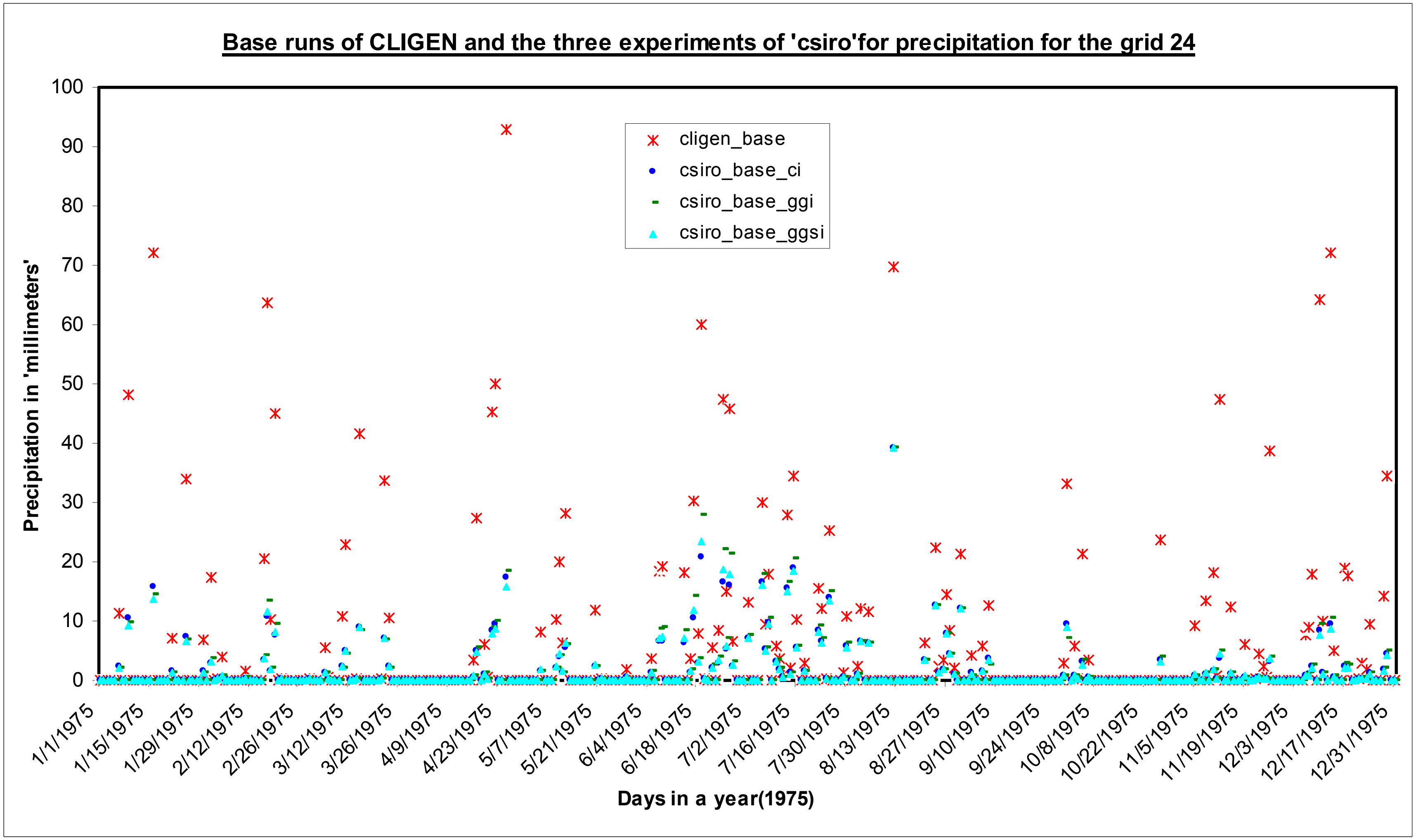

Figure 5.13: Graph showing the base runs of CLIGEN with all the three experiments of 'CSIRO' for precipitation for grid 24 (latitude 30.5, longitude 90.5)

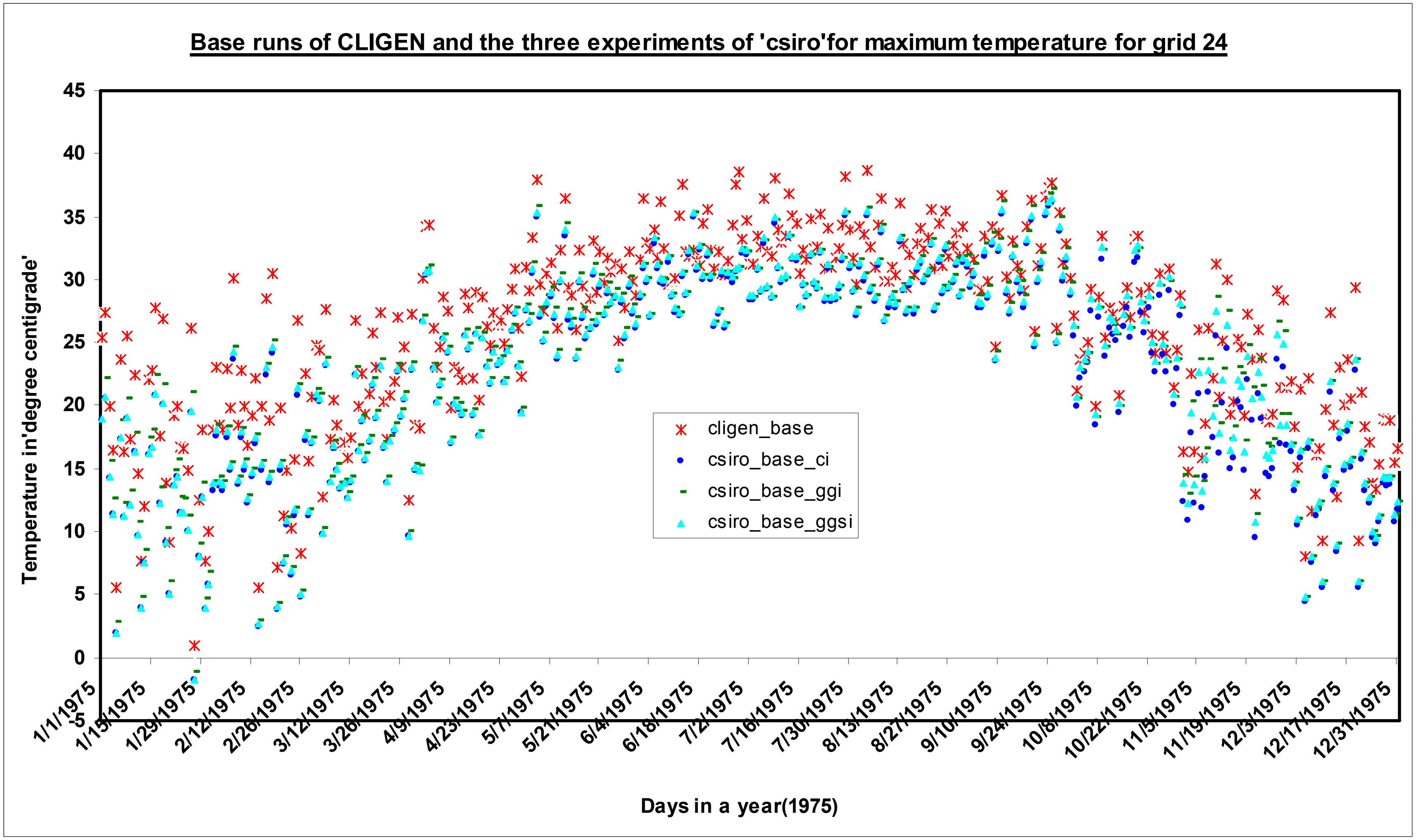

Figure 5.14: Graph showing the base runs of CLIGEN with all the three experiments of 'CSIRO' for maximum temperature for grid 24 (latitude 30.5, longitude 90.5)

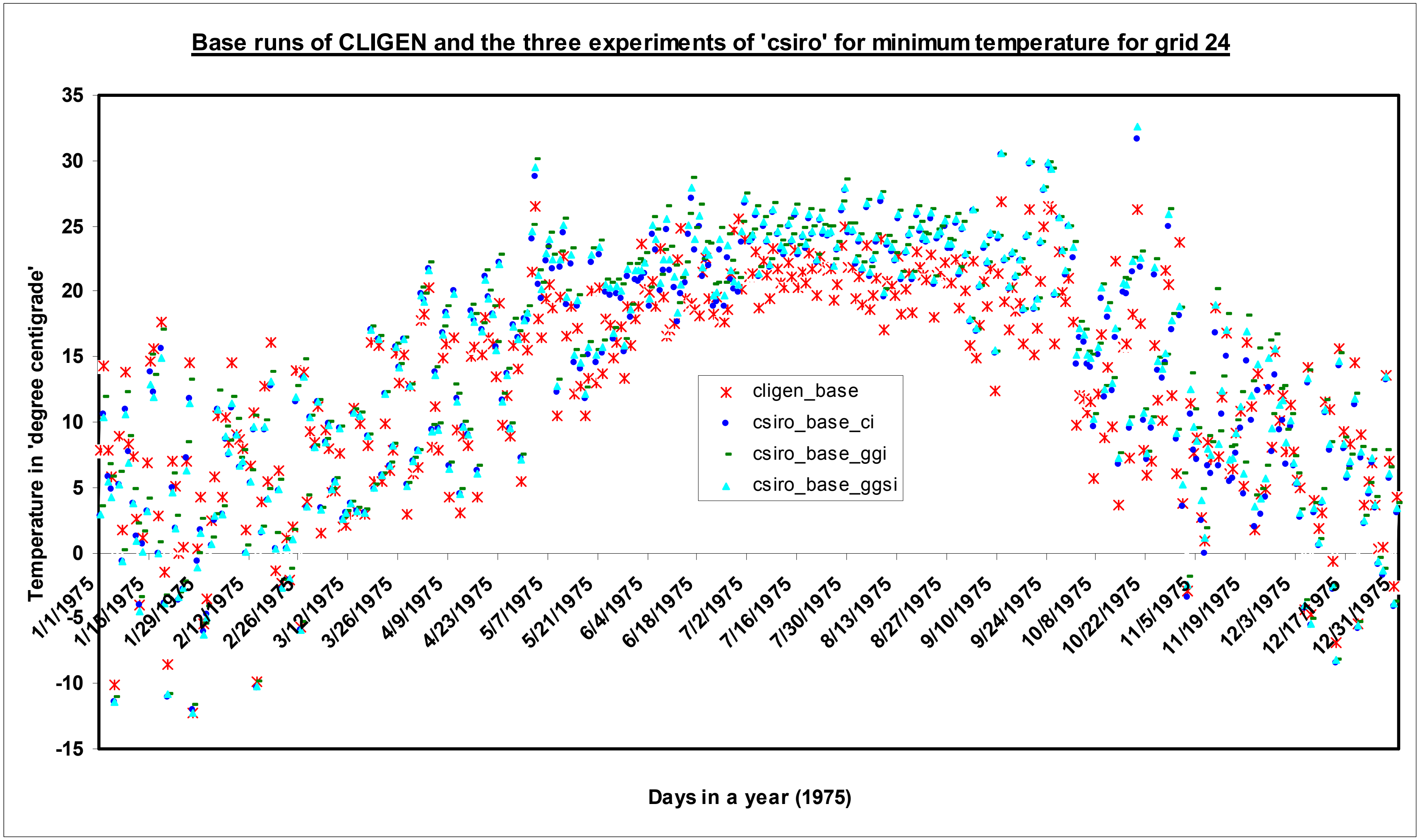

Figure 5.15: Graph showing the base runs of CLIGEN with all the three experiments of 'CSIRO' for minimum temperature for grid 24 (latitude 30.5, longitude 90.5)

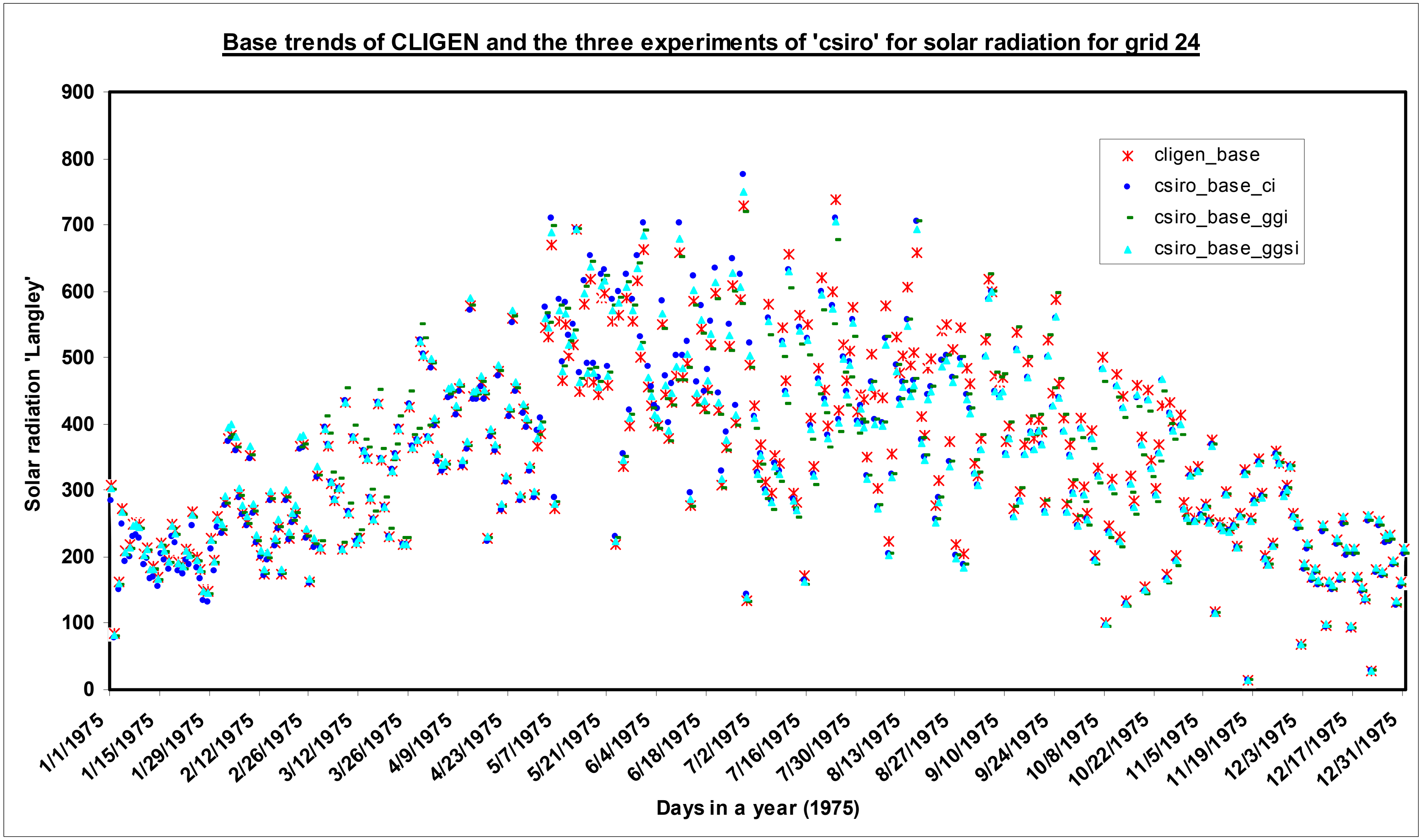

Figure 5.16: Graph showing the base runs of CLIGEN with all the three experiments of 'CSIRO' for solar radiation for grid 24 (latitude 30.5, longitude 90.5)

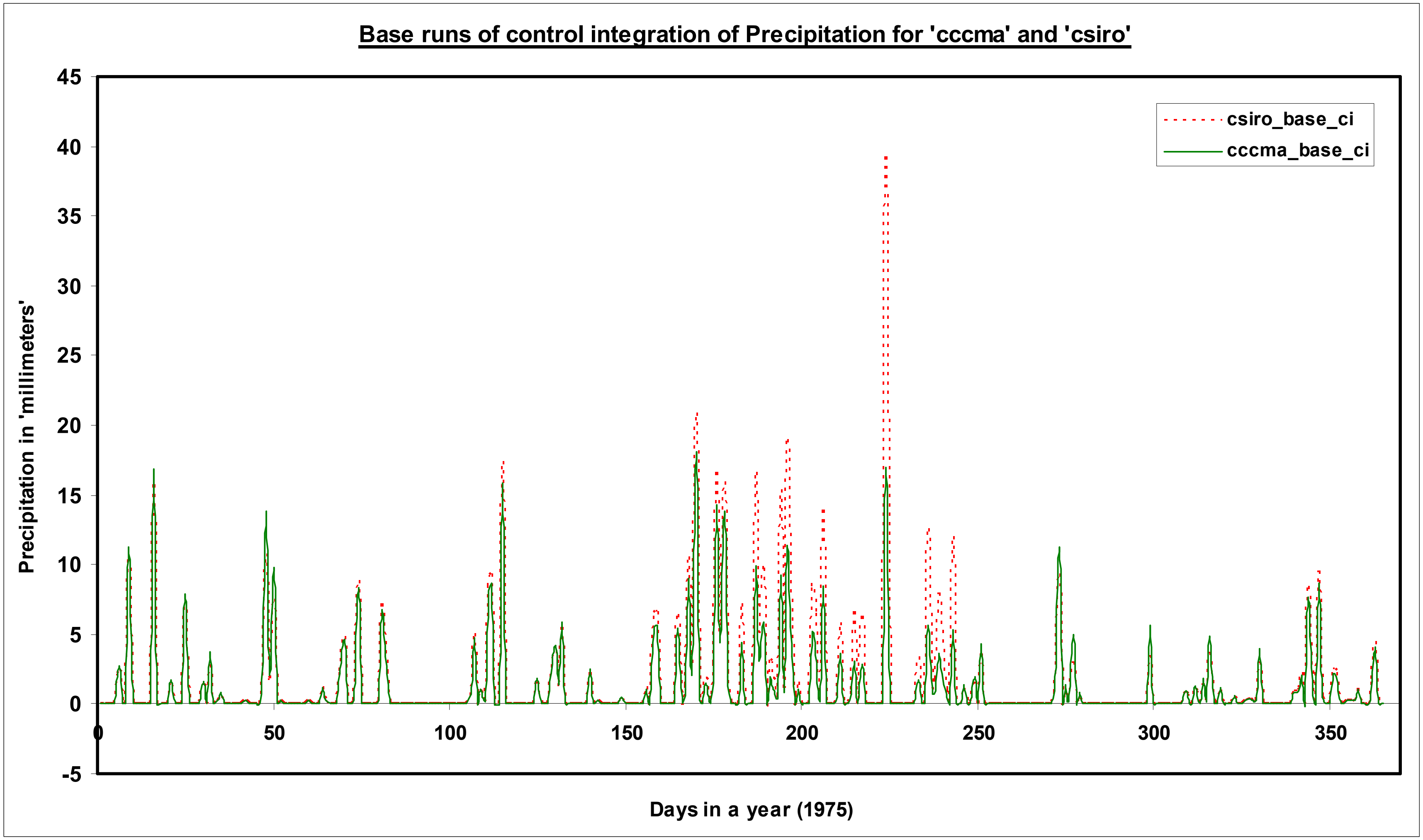

Figure 5.17: Graph showing the base runs of control integration of precipitation for ‘CCCma’ and ‘CSIRO’

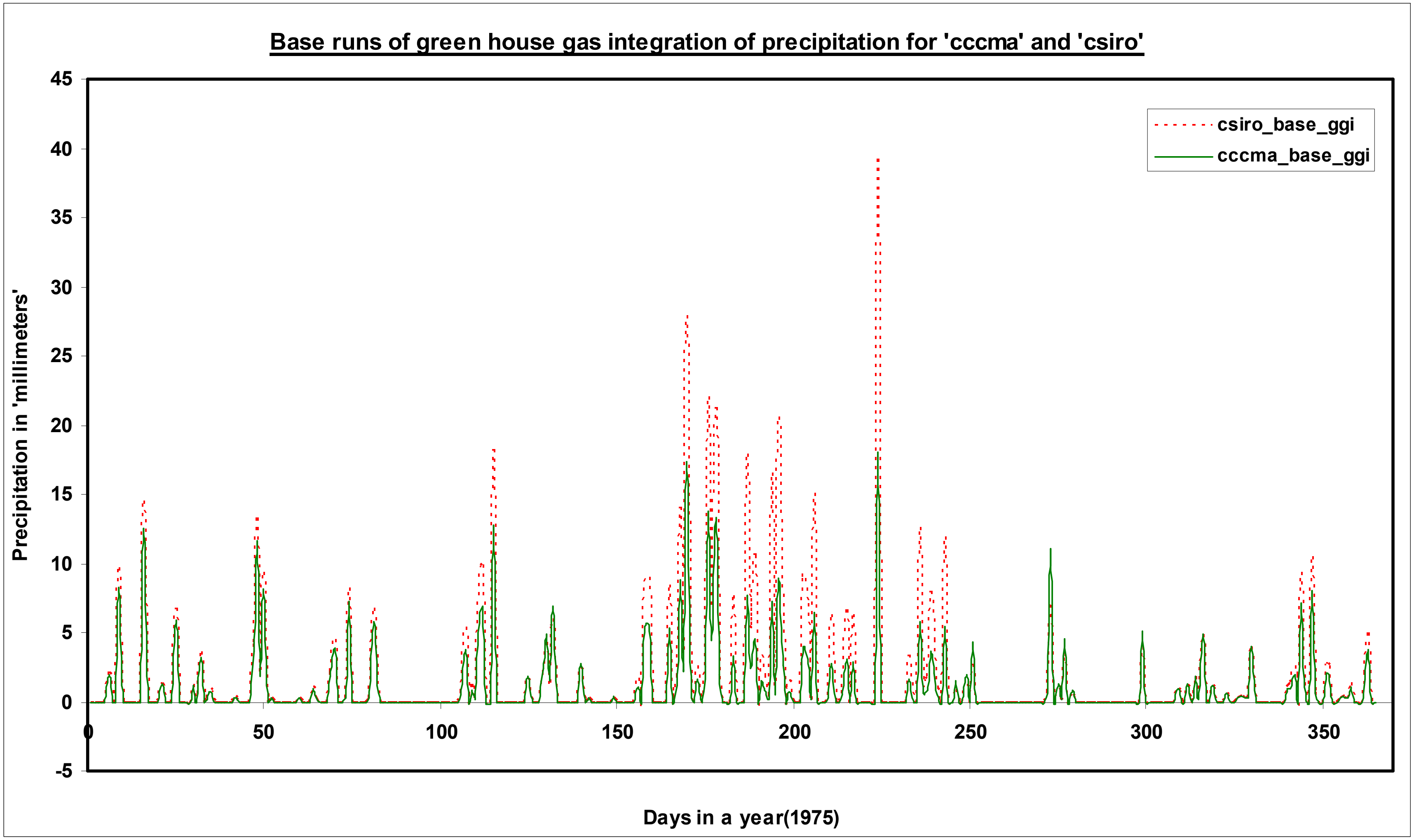

Figure 5.18: Graph showing the base runs of green house gas integration of precipitation for 'CCCma' and 'CSIRO'

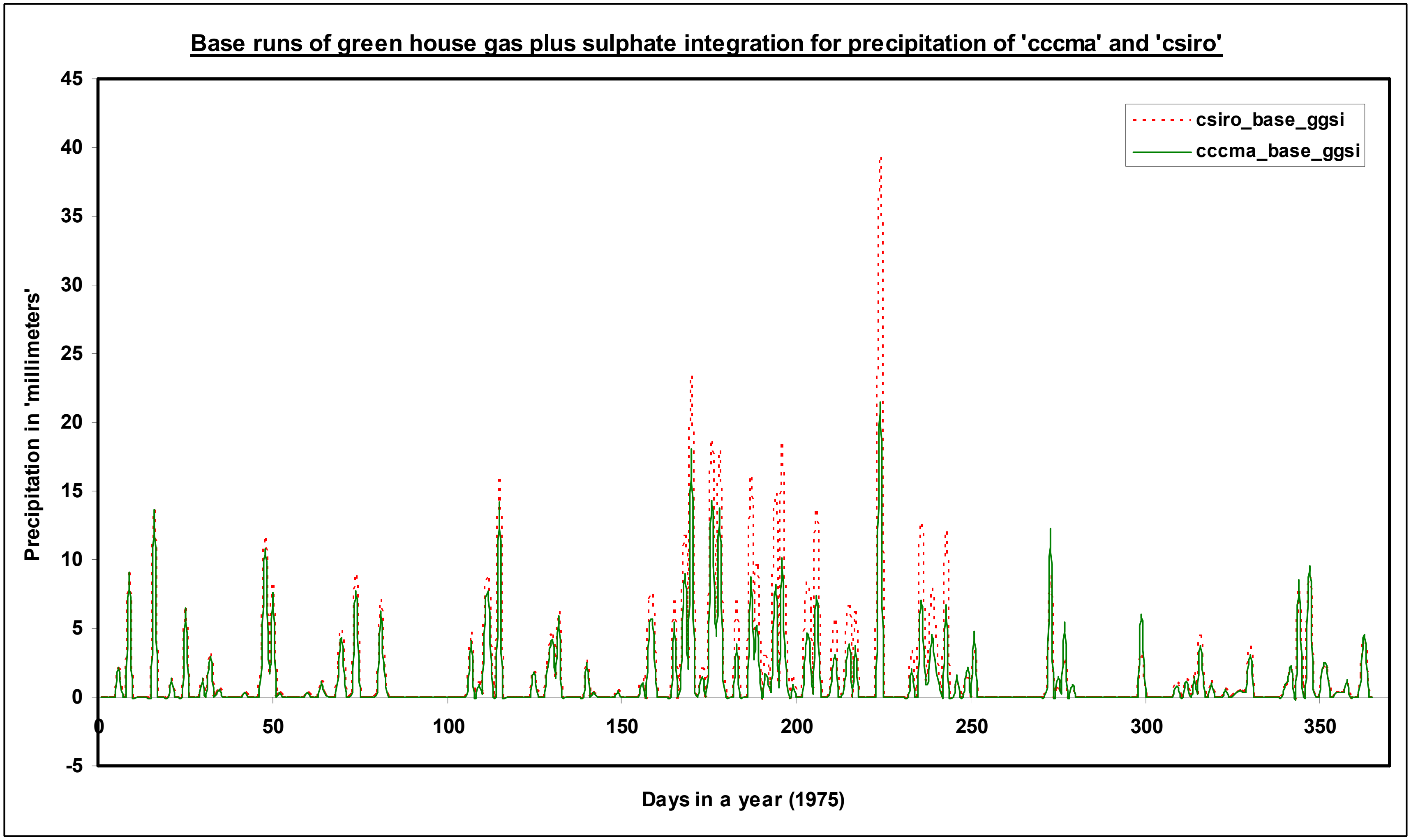

Figure 5.19: Graph showing the base runs of green house gas plus sulphate integration of precipitation for 'CCCma' and 'CSIRO'

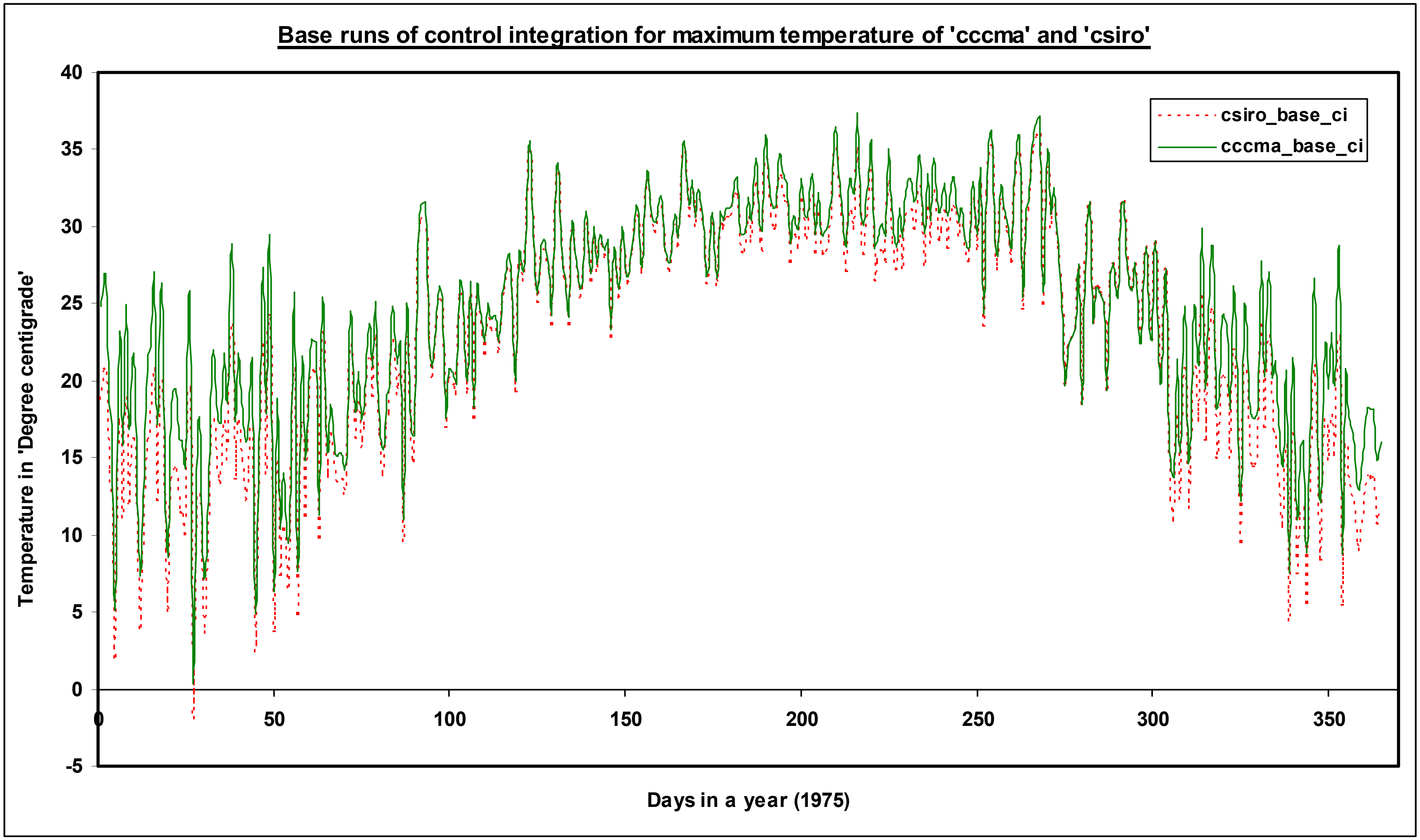

Figure 5.20: Graph showing the base runs of control integration of maximum temperature for 'CCCma' and 'CSIRO'

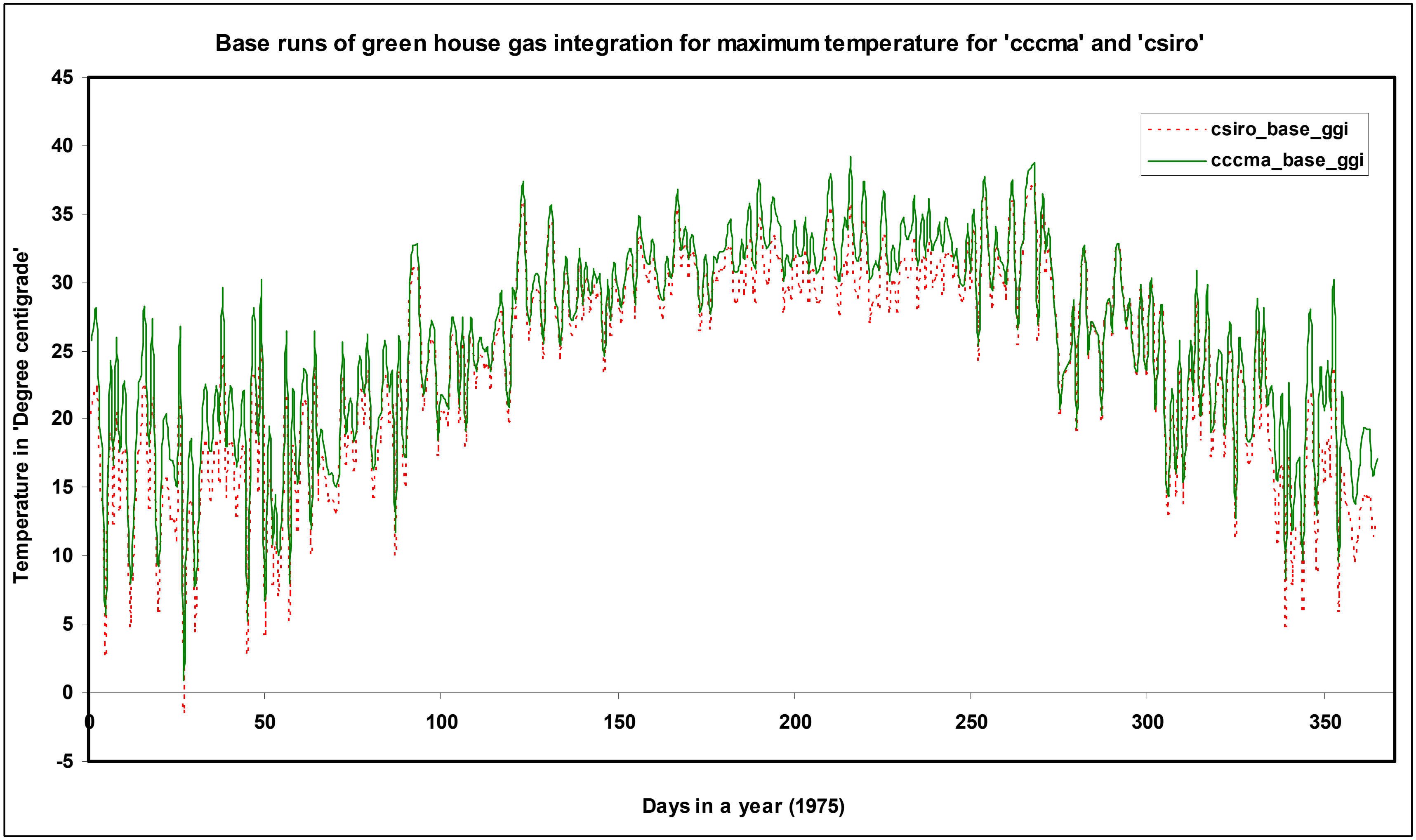

Figure 5.21: Graph showing the base runs of green house gas integration of maximum temperature for 'CCCma' and 'CSIRO'

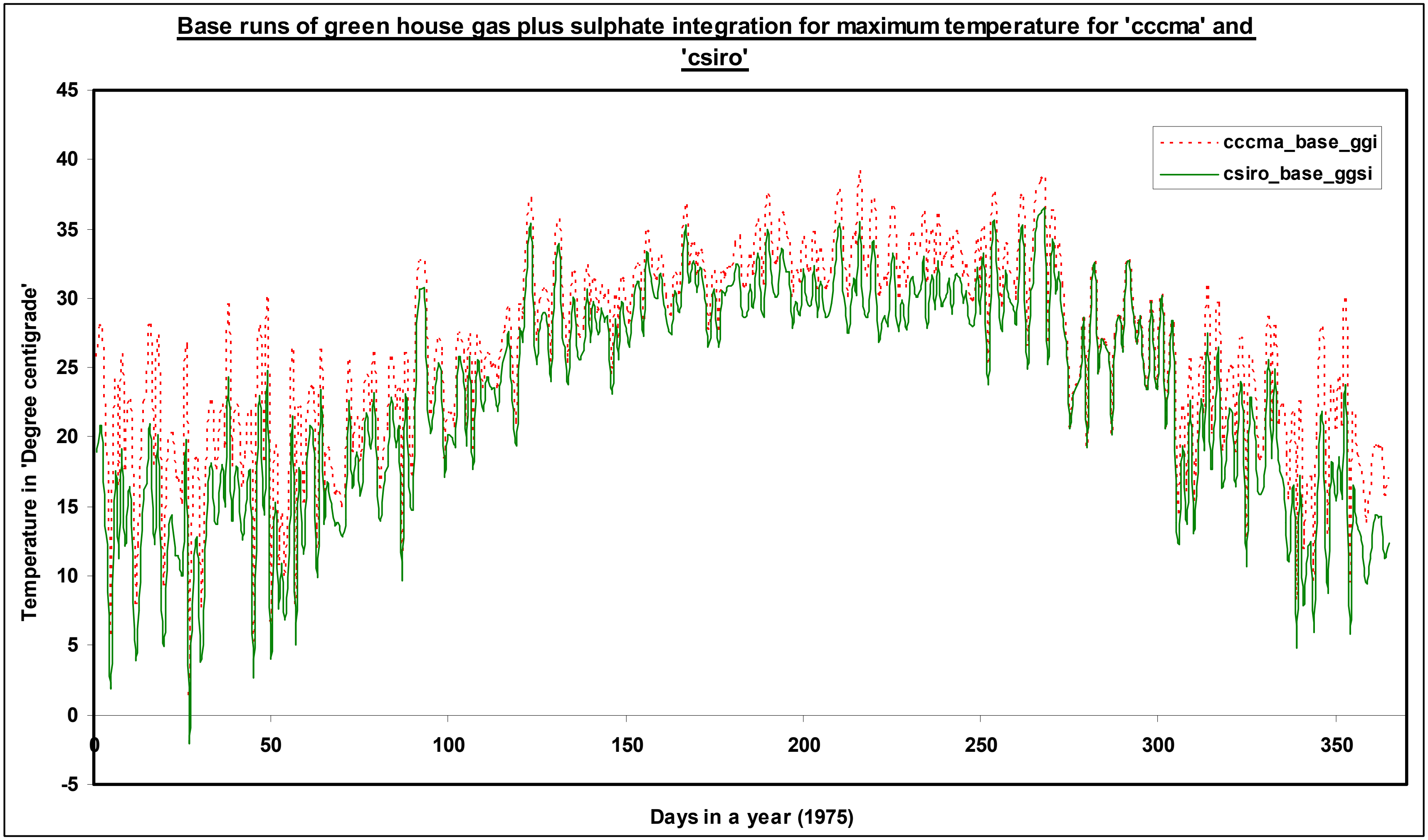

Figure 5.22: Graph showing the base runs of green house gas plus sulphate integration of maximum temperature for 'CCCma' and 'CSIRO'

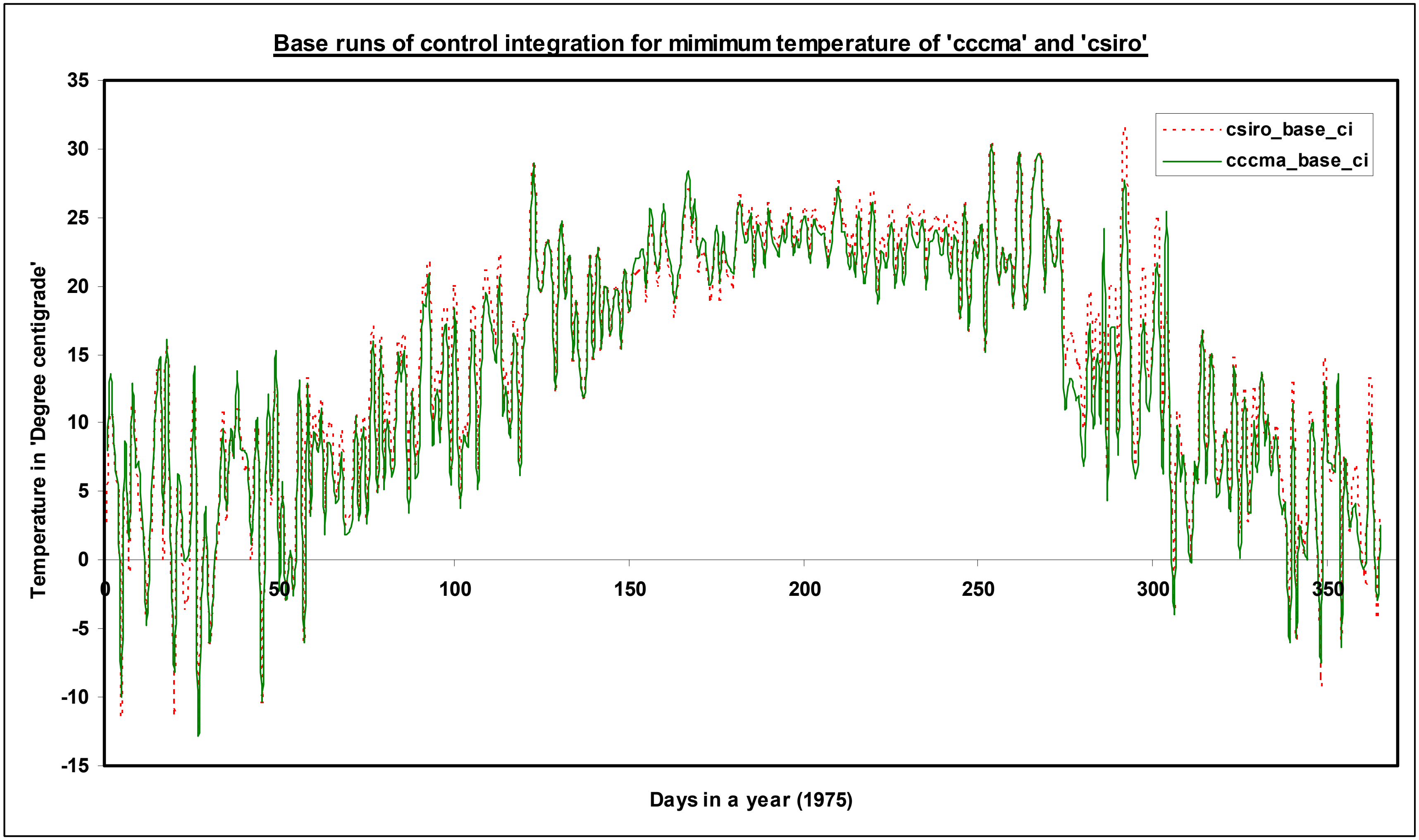

Figure 5.23: Graph showing the base runs of control integration of minimum temperature for 'CCCma' and 'CSIRO'

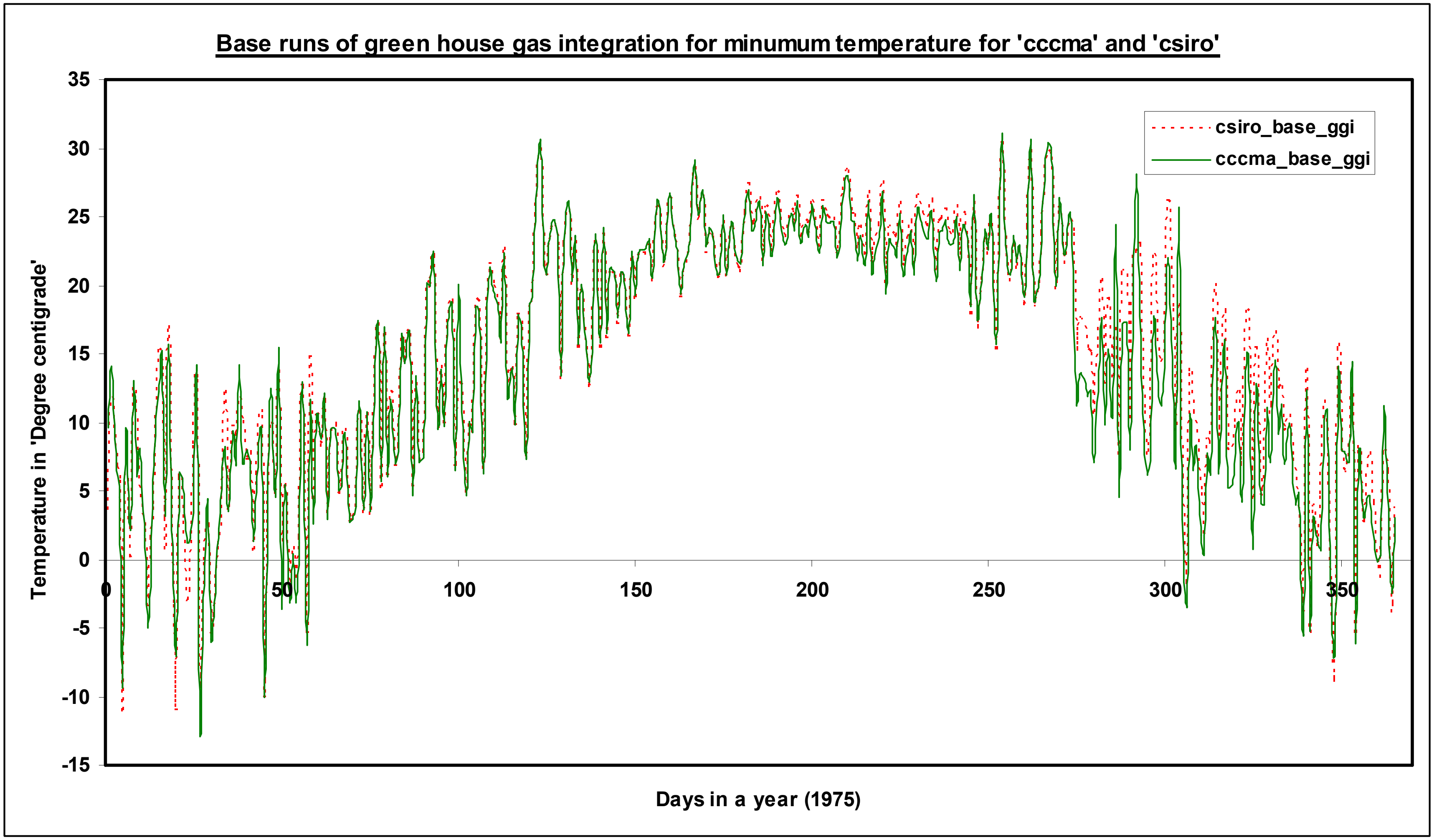

Figure 5.24: Graph showing the base runs of green house gas integration of minimum temperature for 'CCCma' and 'CSIRO'

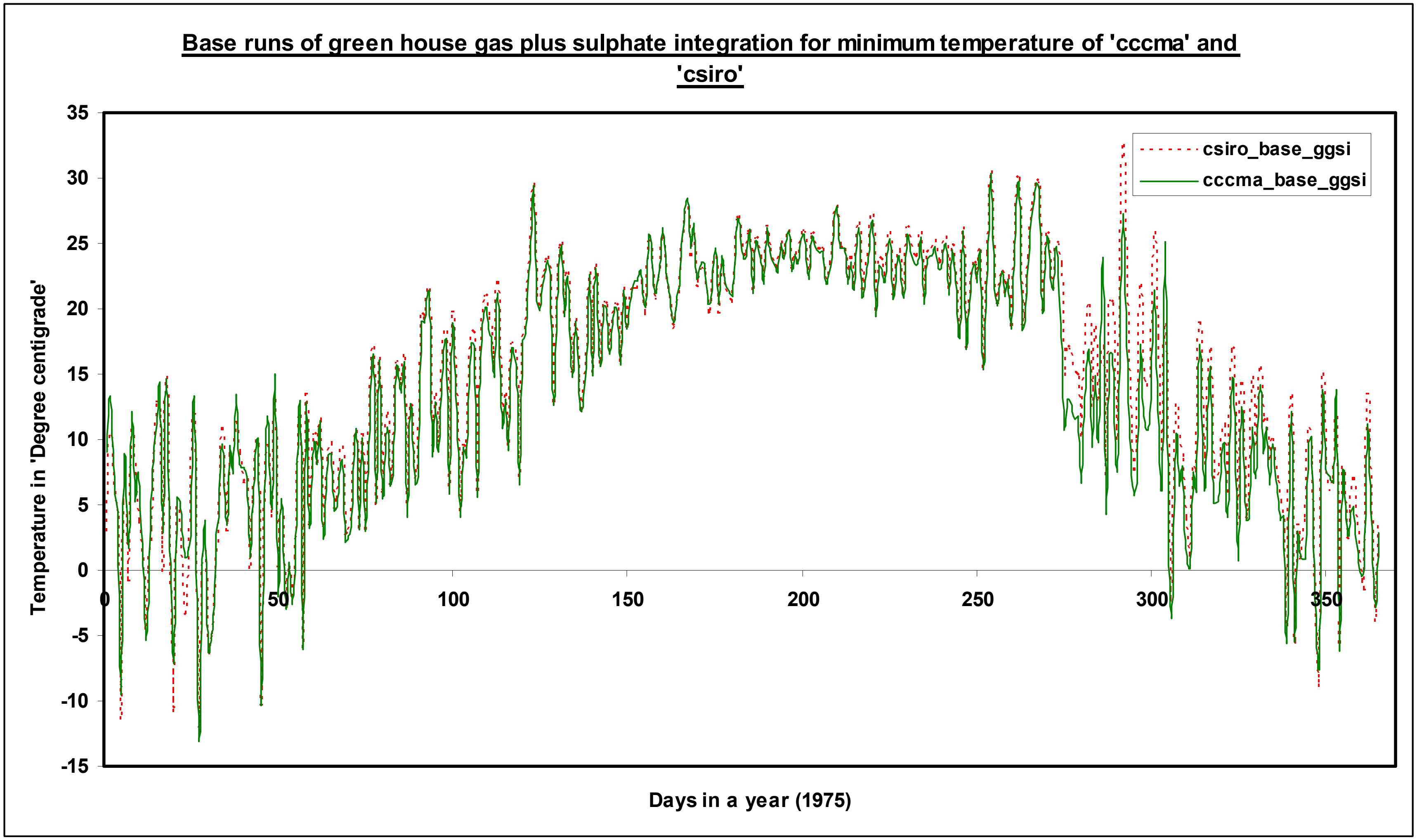

Figure 5.25: Graph showing the base runs of green house gas plus sulphate integration of minimum temperature for 'CCCma' and 'CSIRO'

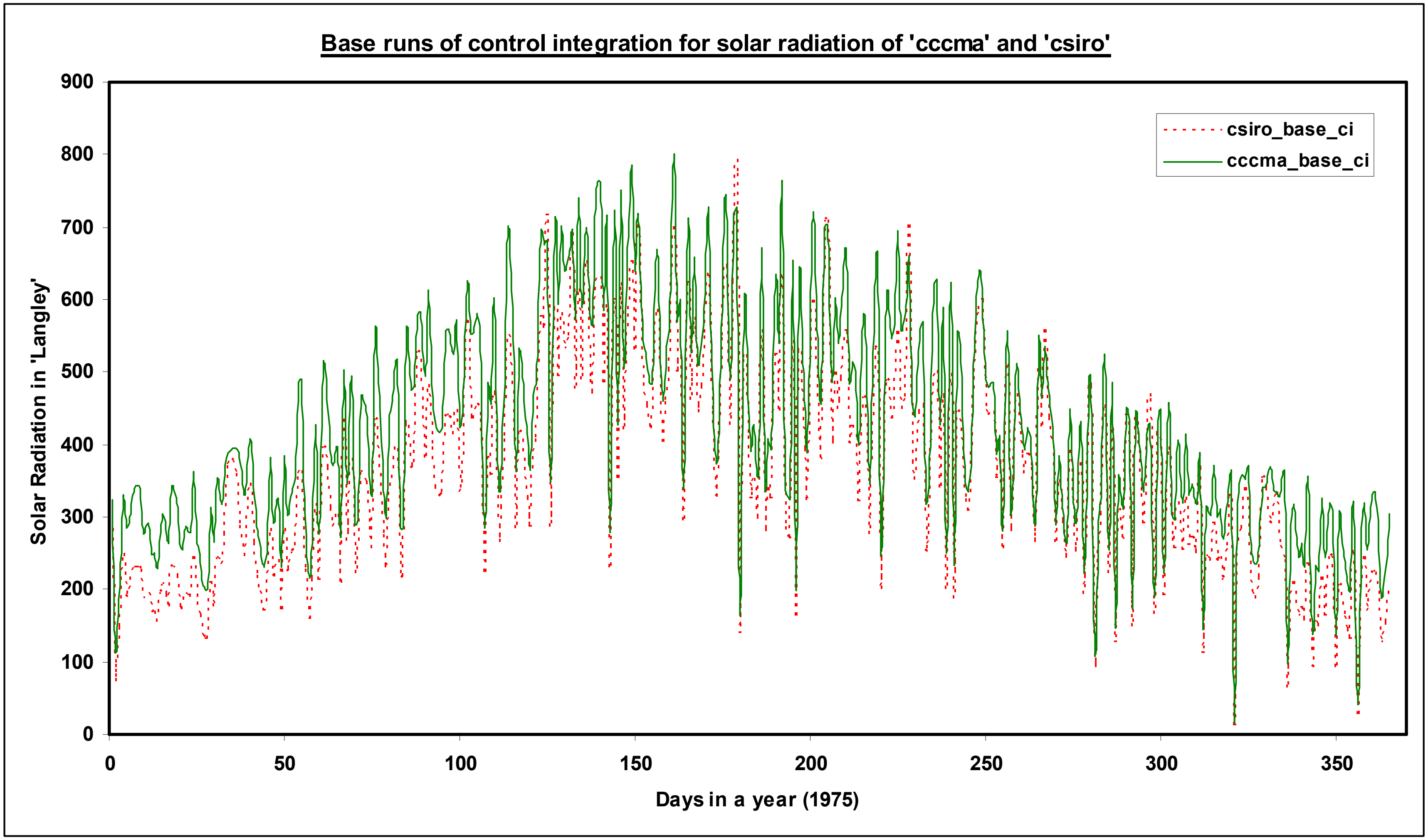

Figure 5.26: Graph showing the base runs of control integration of solar radiation for ‘CCCma’ and ‘CSIRO’

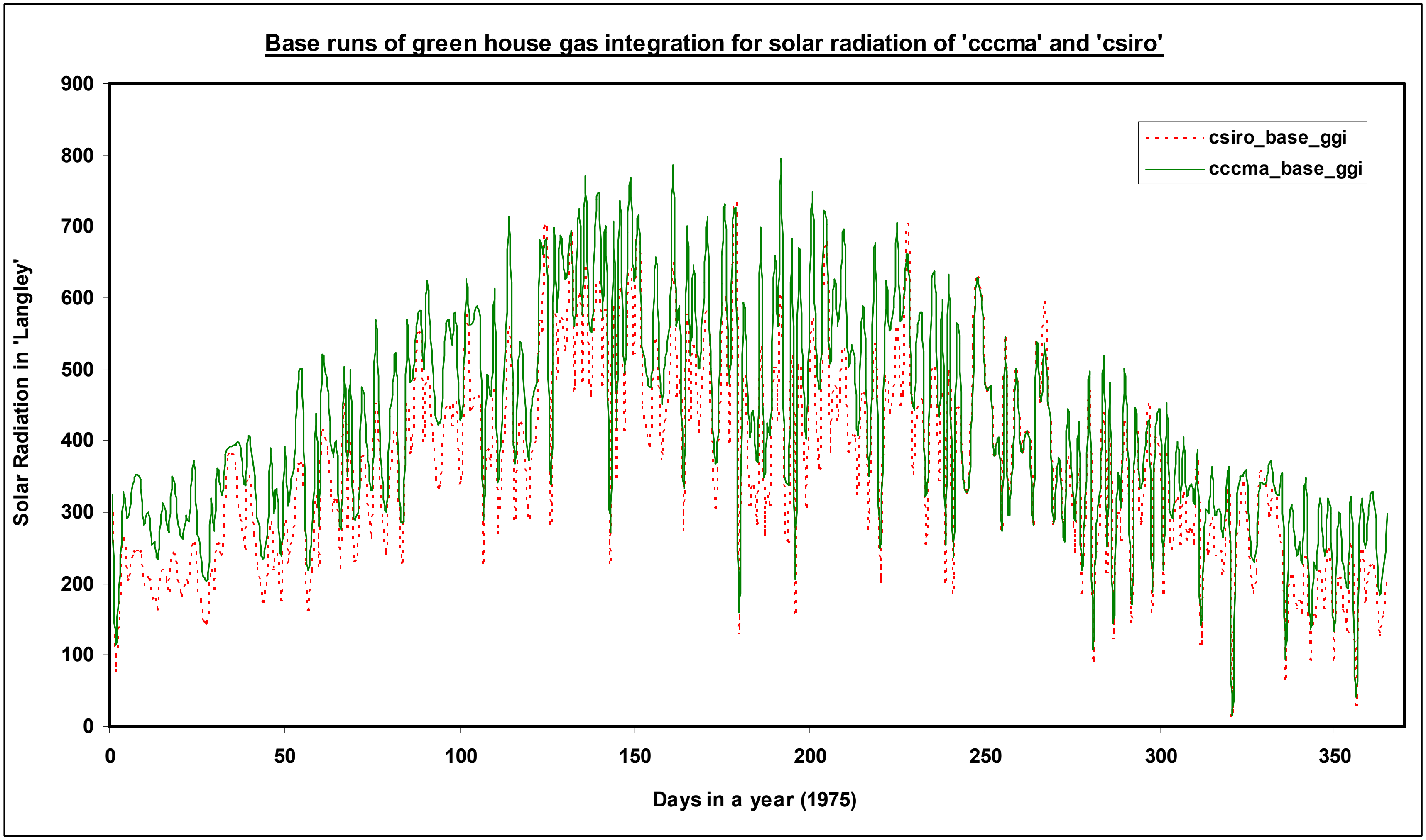

Figure 5.27: Graph showing the base runs of green house gas integration of solar radiation for 'CCCma' and 'CSIRO'

Figure 5.28: Graph showing the base runs of green house gas plus sulphate integration of solar radiation for 'CCCma' and 'CSIRO'

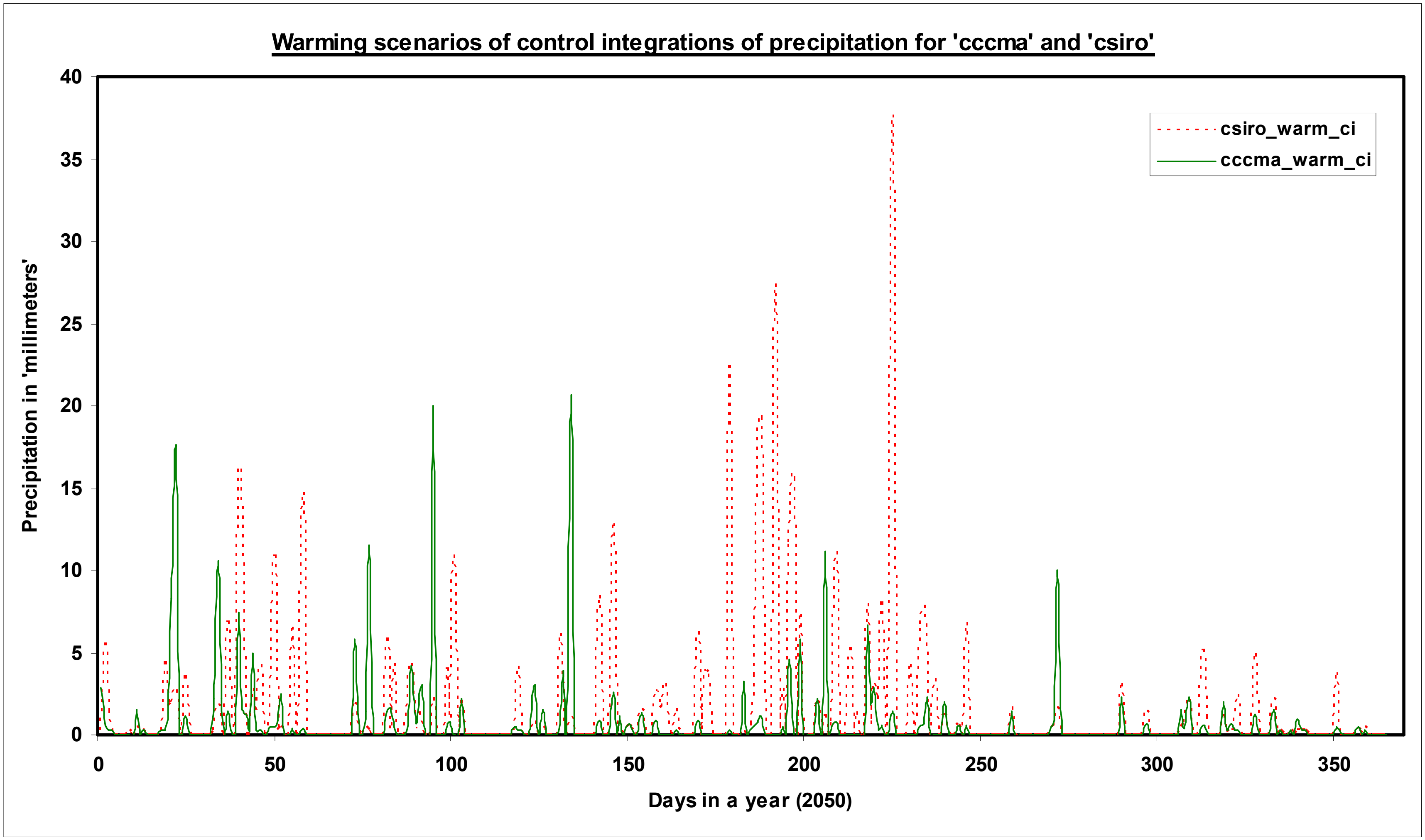

Figure 5.29: Graph showing the warming scenarios of control integration of precipitation for 'CCCma' and 'CSIRO'

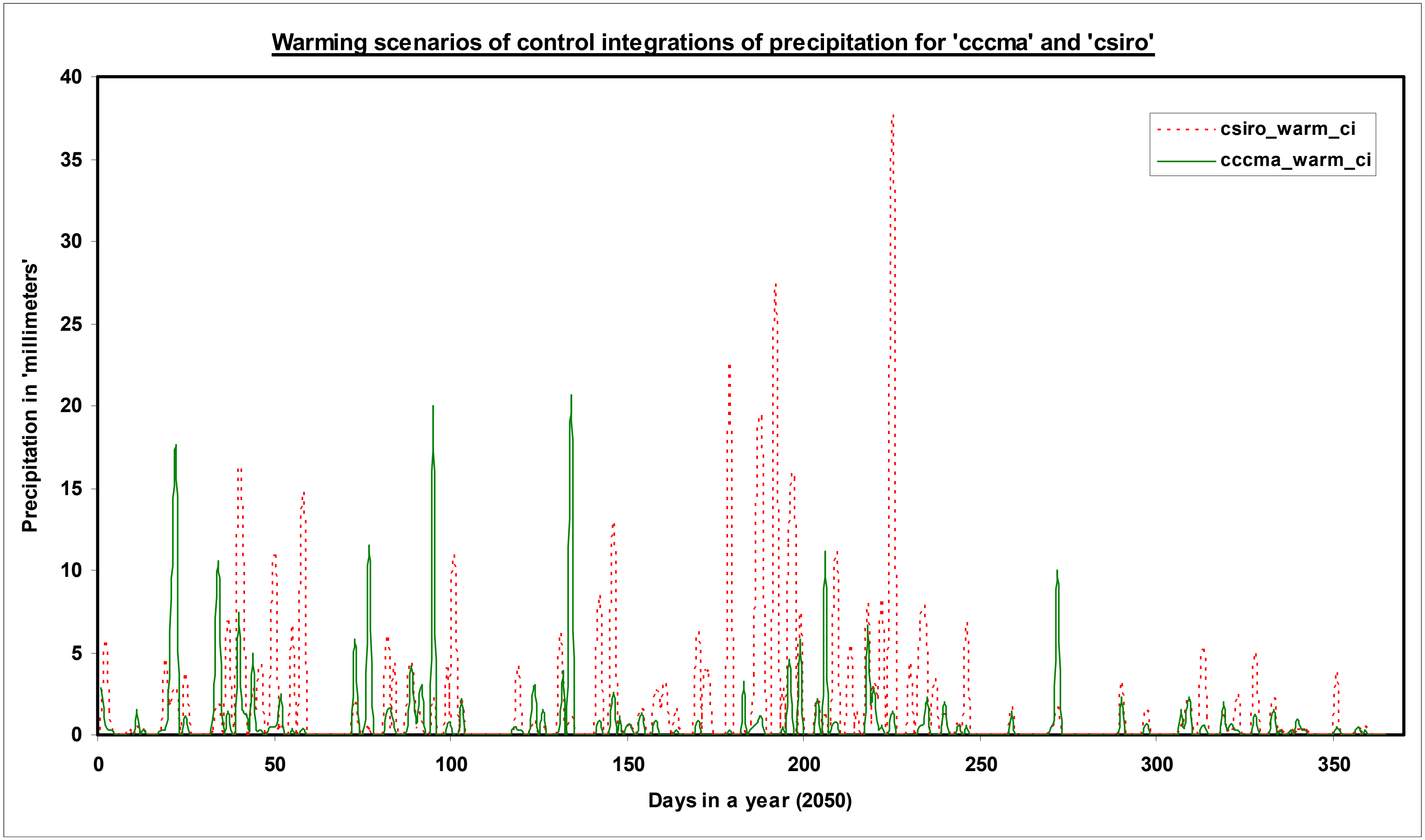

Figure 5.30: Graph showing the warming scenarios of green house gas integration of precipitation for 'CCCma' and 'CSIRO'

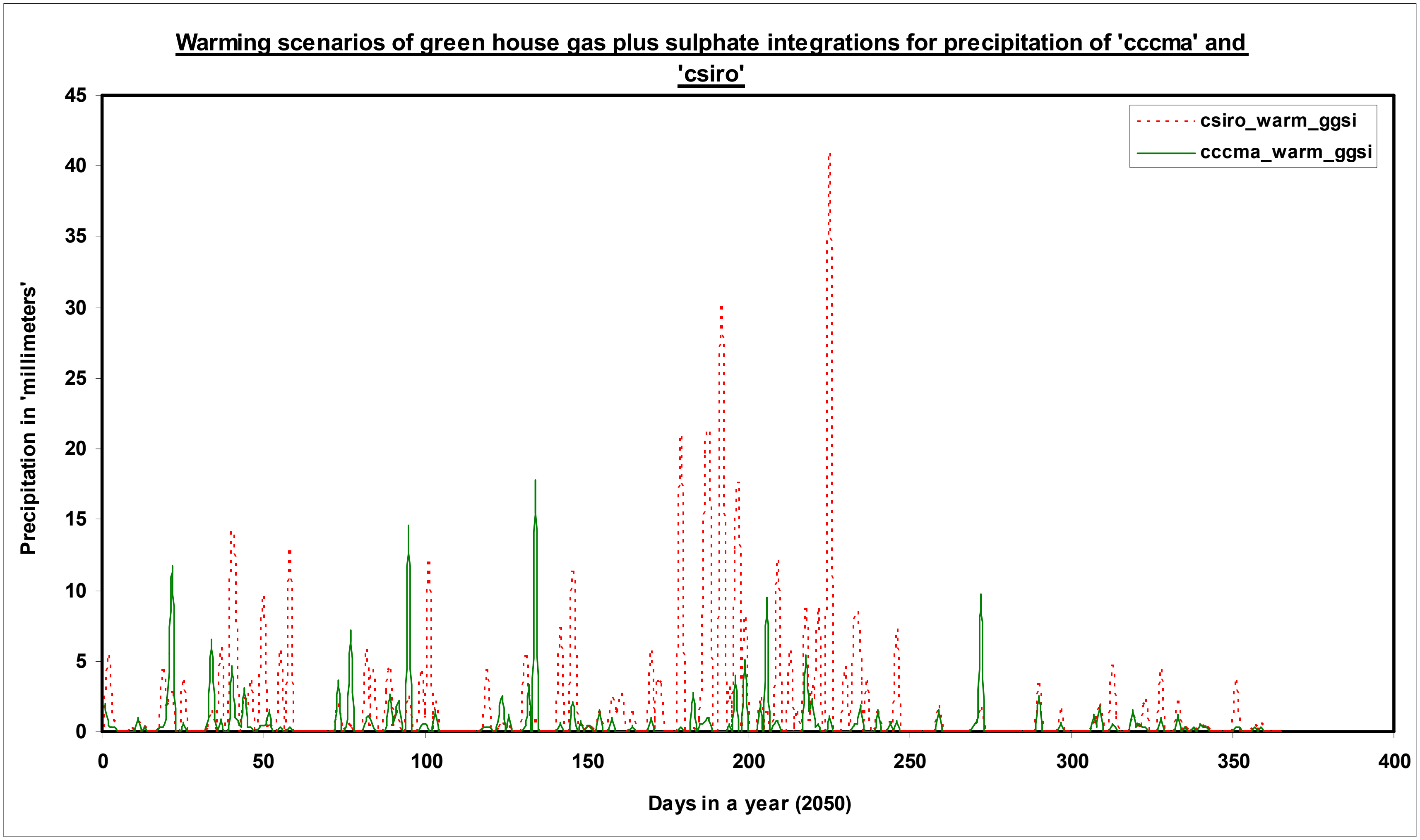

Figure 5.31: Graph showing the warming scenarios of green house gas plus sulphate integration of precipitation for 'CCCma' and 'CSIRO'

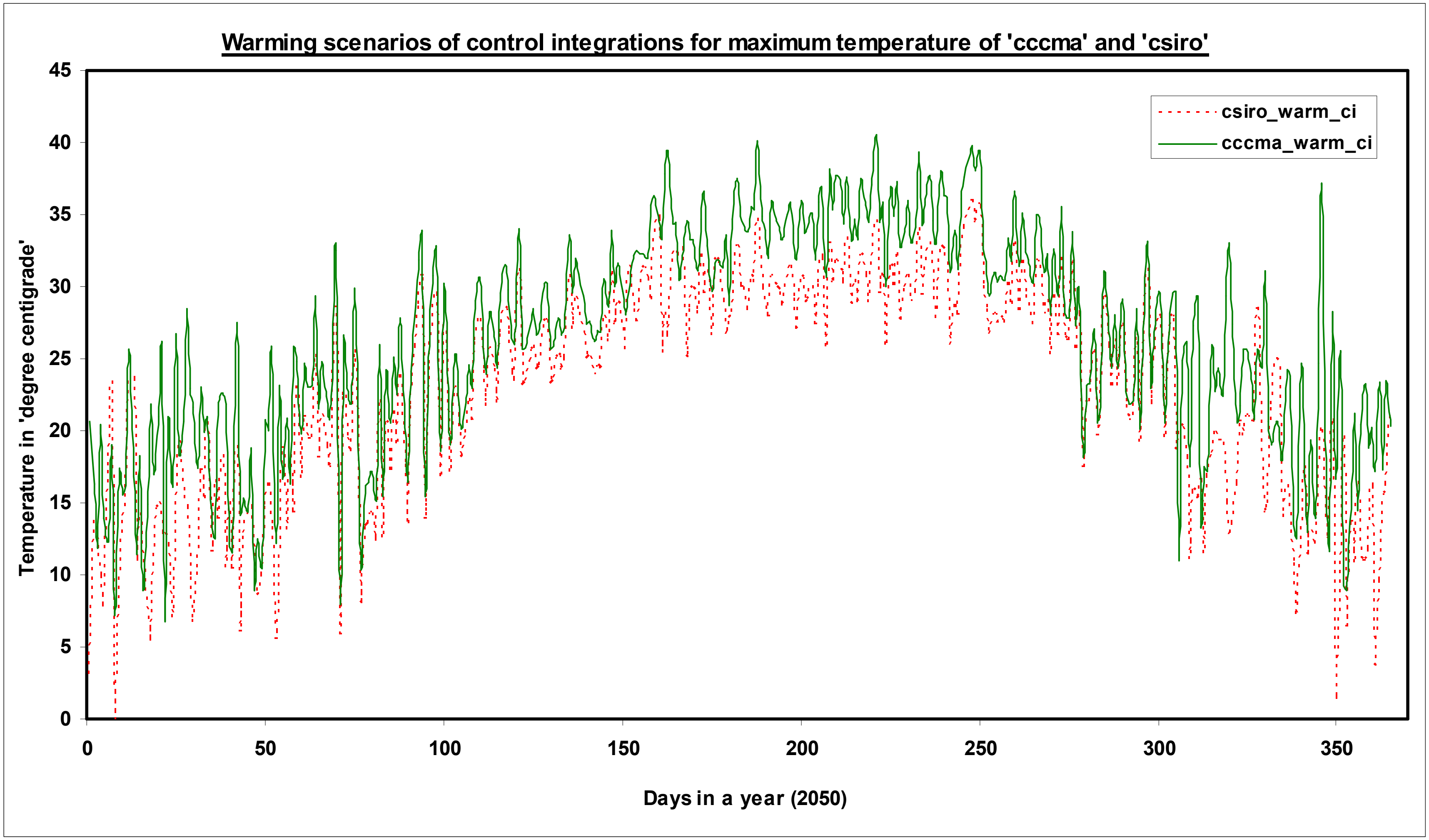

Figure 5.32: Graph showing the warming scenarios of control integration of maximum temperatures for 'CCCma' and 'CSIRO'

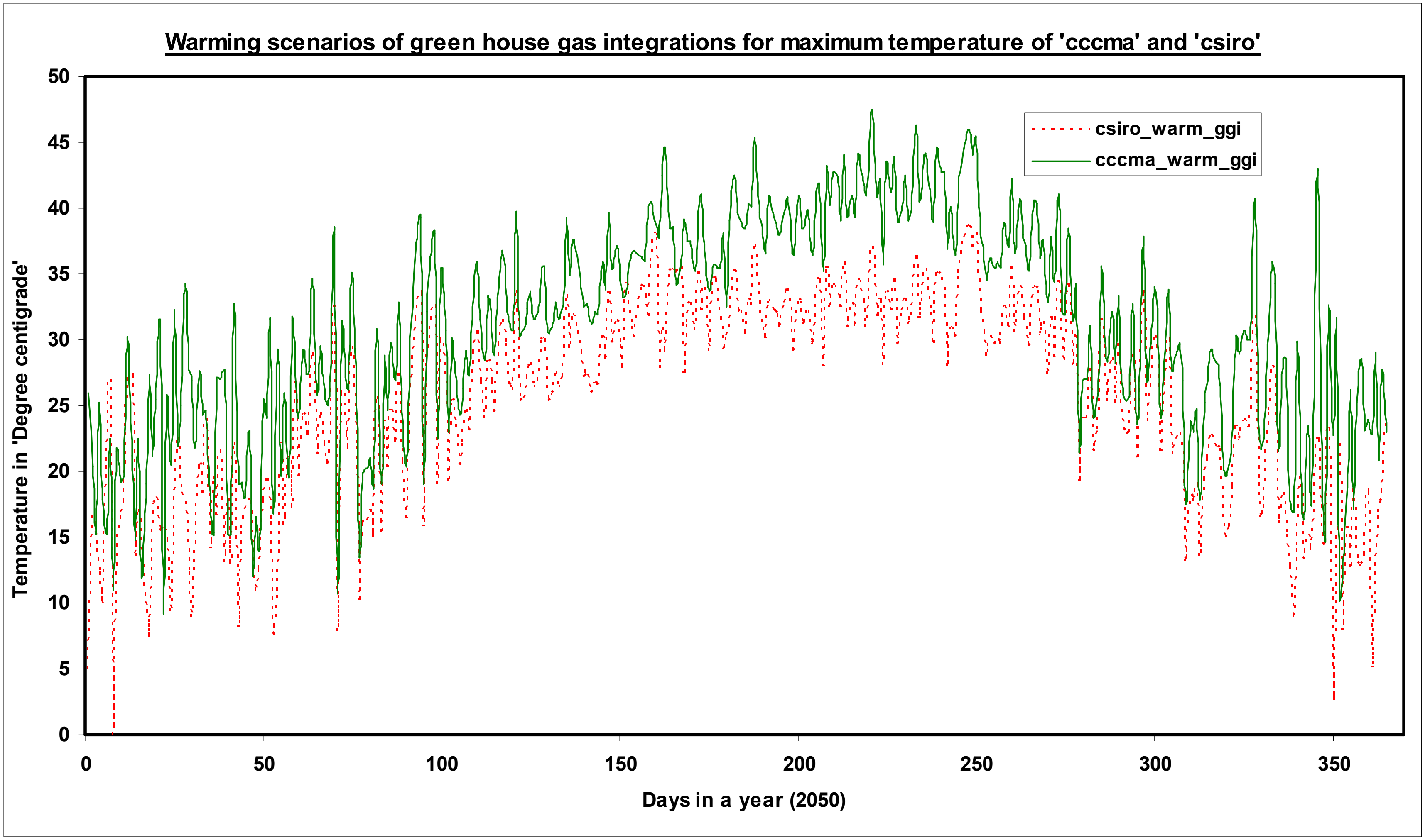

Figure 5.33: Graph showing the warming scenarios of green house gas integration of maximum temperatures for 'CCCma' and 'CSIRO'

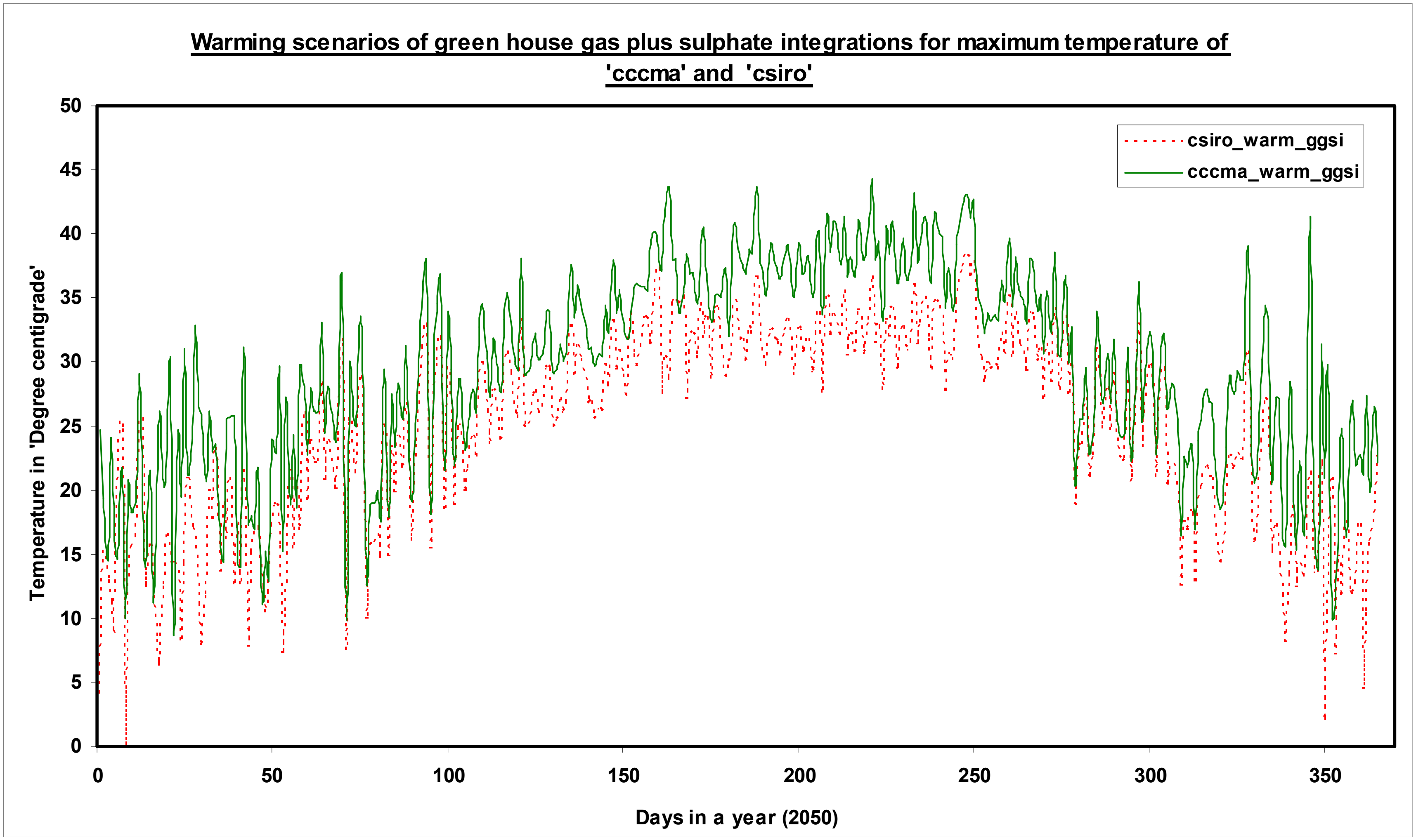

Figure 5.34: Graph showing the warming scenarios of green house gas plus sulphate integration of maximum temperatures for 'CCCma' and 'CSIRO'

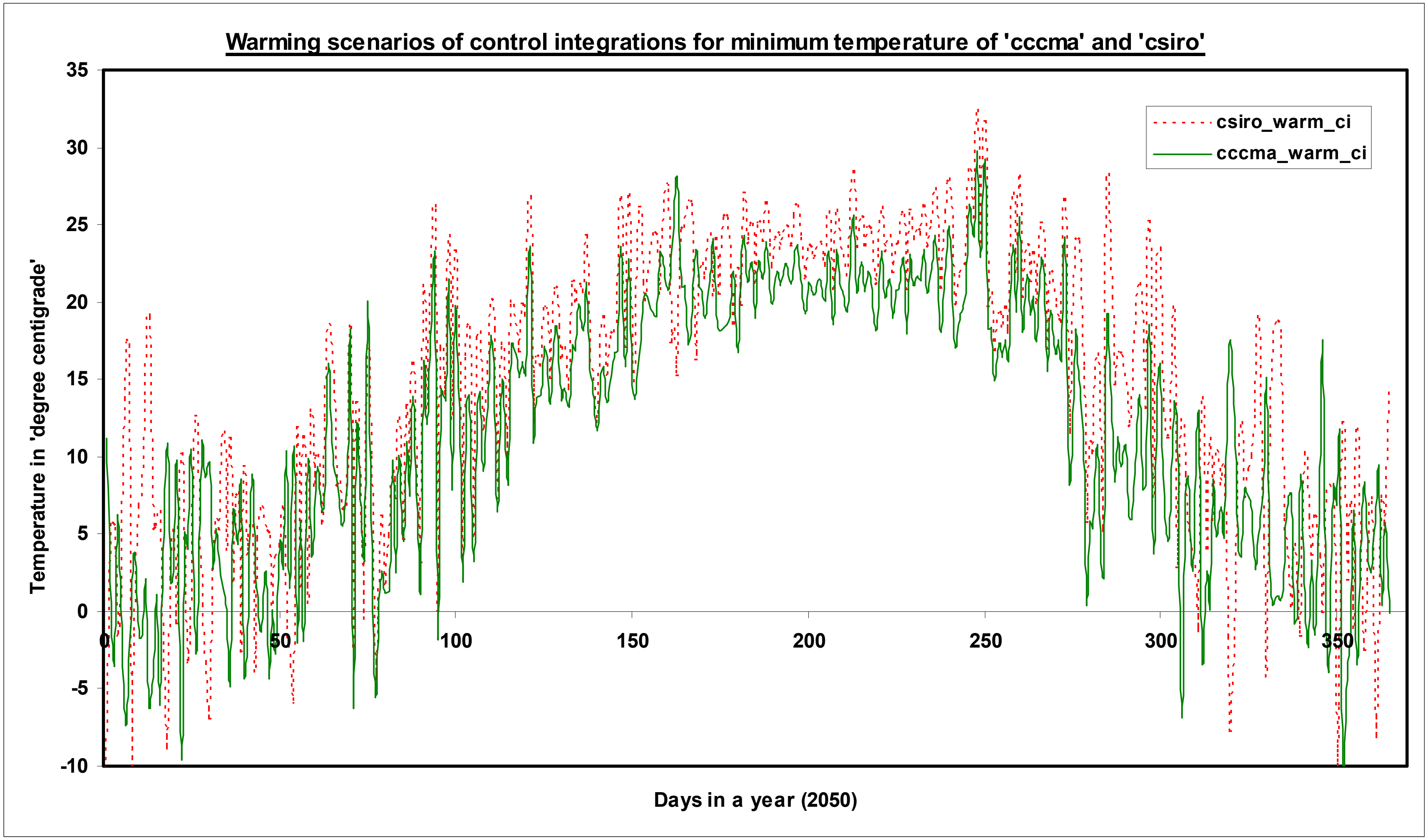

Figure 5.35: Graph showing the warming scenarios of control integration of minimum temperatures for ‘CCCma’ and ‘CSIRO’

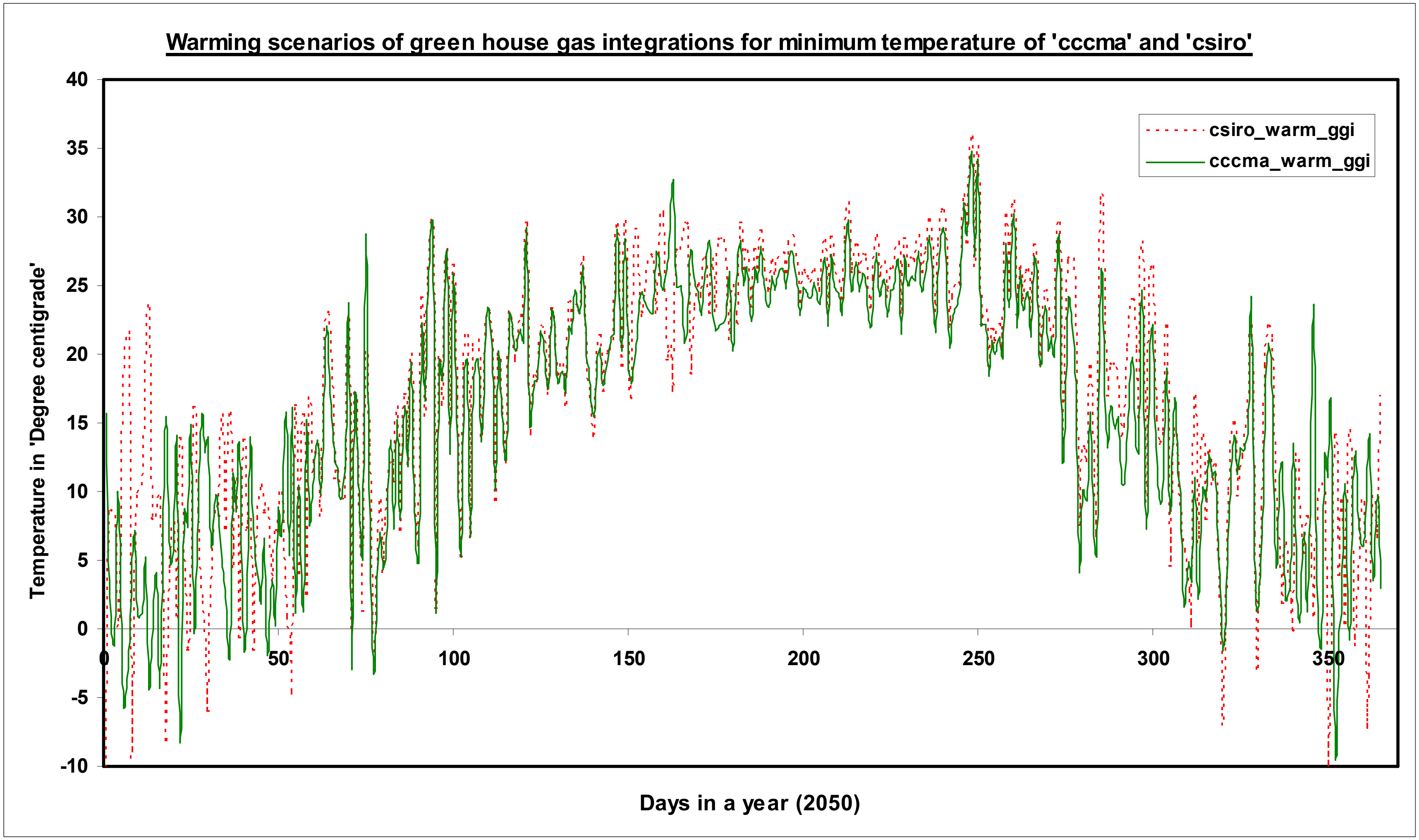

Figure 5.36: Graph showing the warming scenarios of green house gas integration of minimum temperatures for 'CCCma' and 'CSIRO'

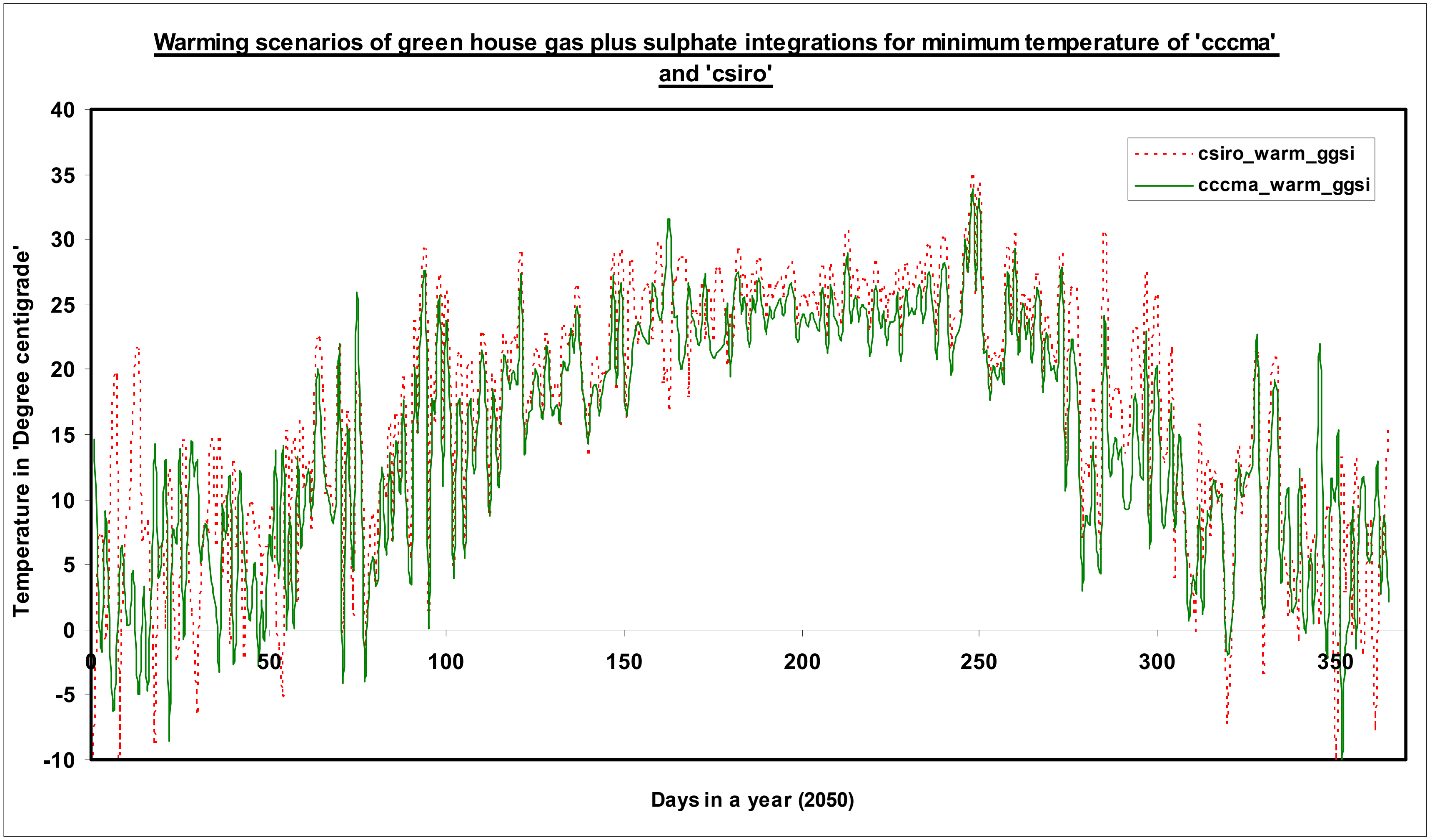

Figure 5.37: Graph showing the warming scenarios of green house gas plus sulphate integration of minimum temperatures for 'CCCma' and 'CSIRO'

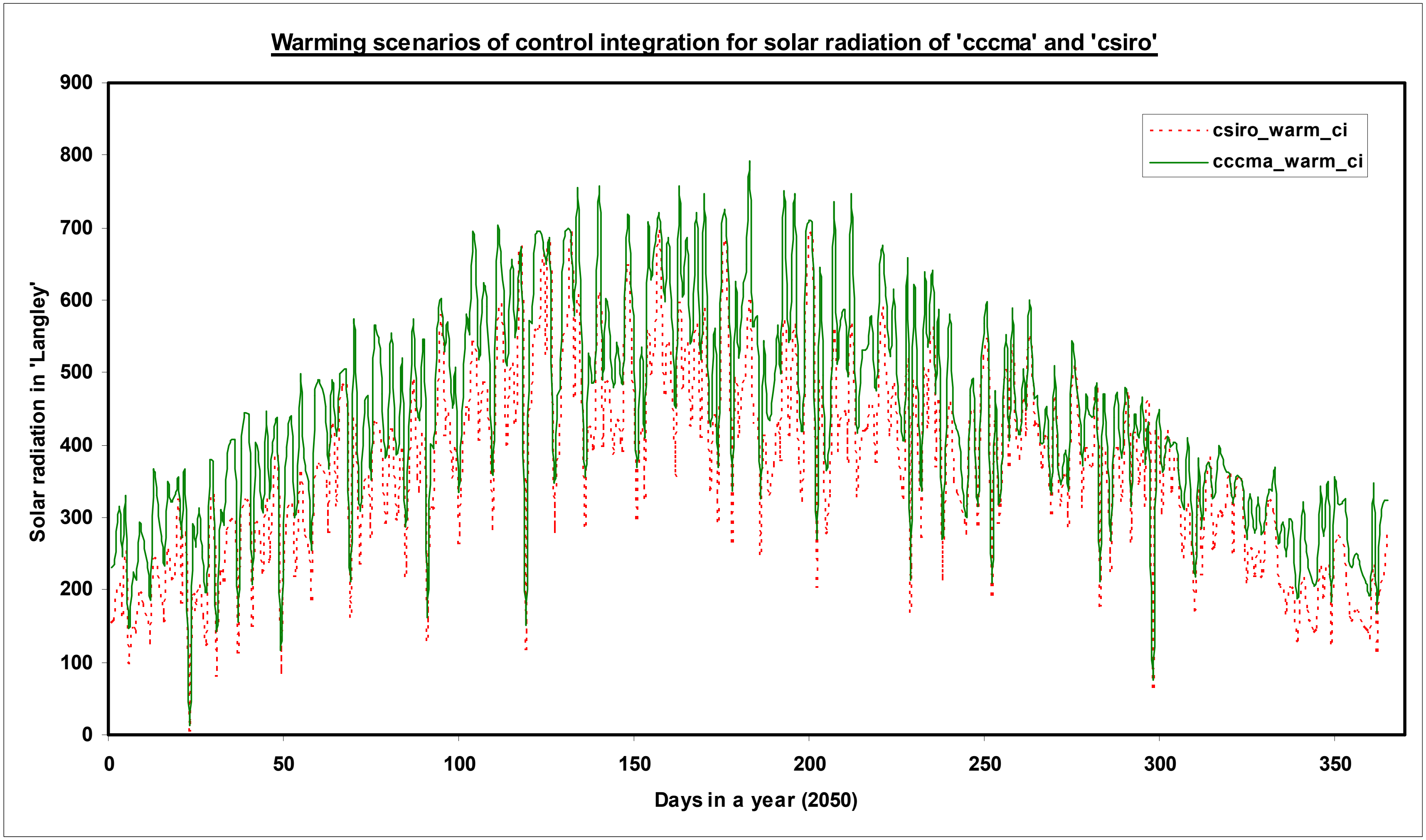

Figure 5.38: Graph showing the warming scenarios of control integration of solar radiation for 'CCCma' and 'CSIRO'

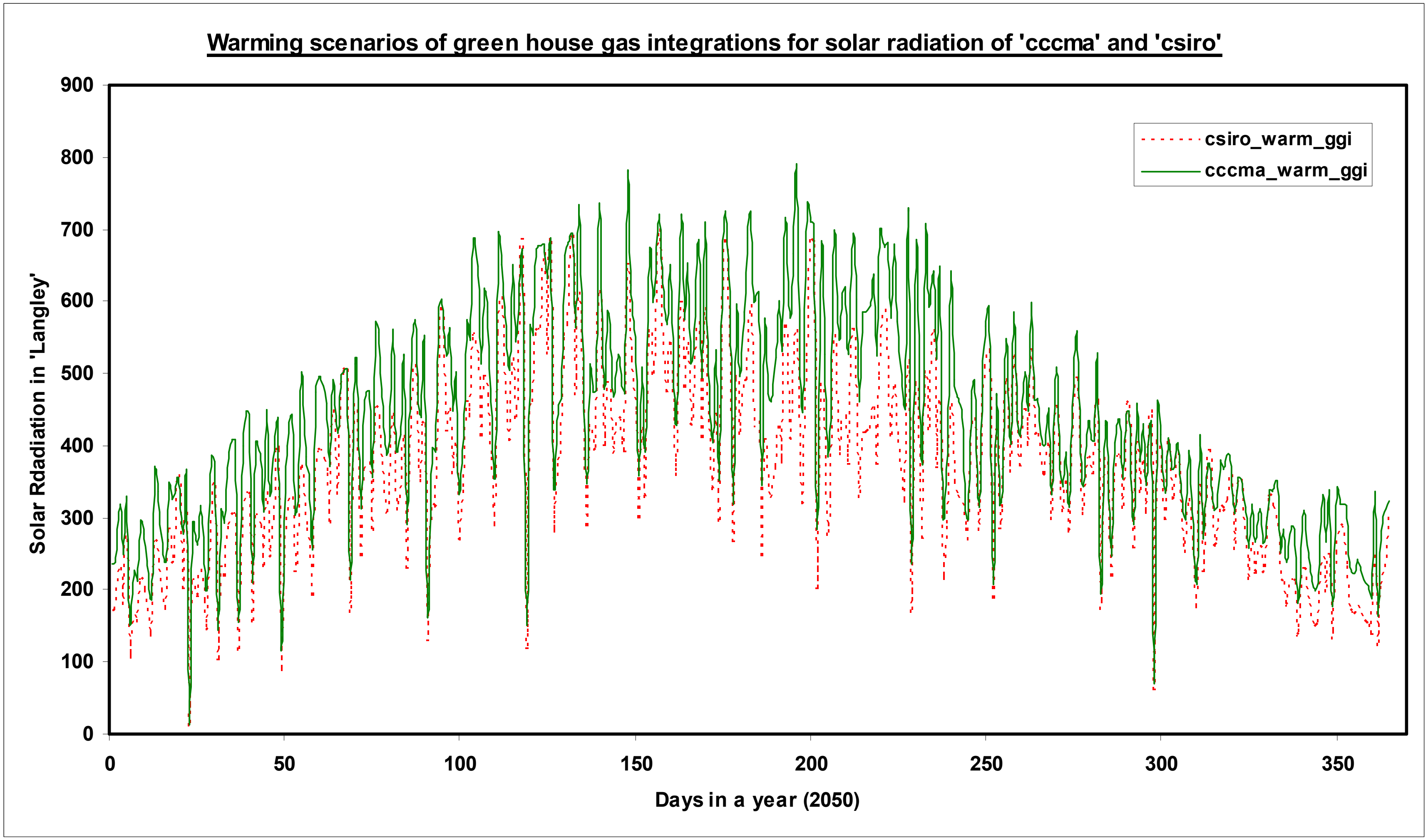

Figure 5.39: Graph showing the warming scenarios of green house gas integration of solar radiation for ‘CCCma’ and ‘CSIRO’

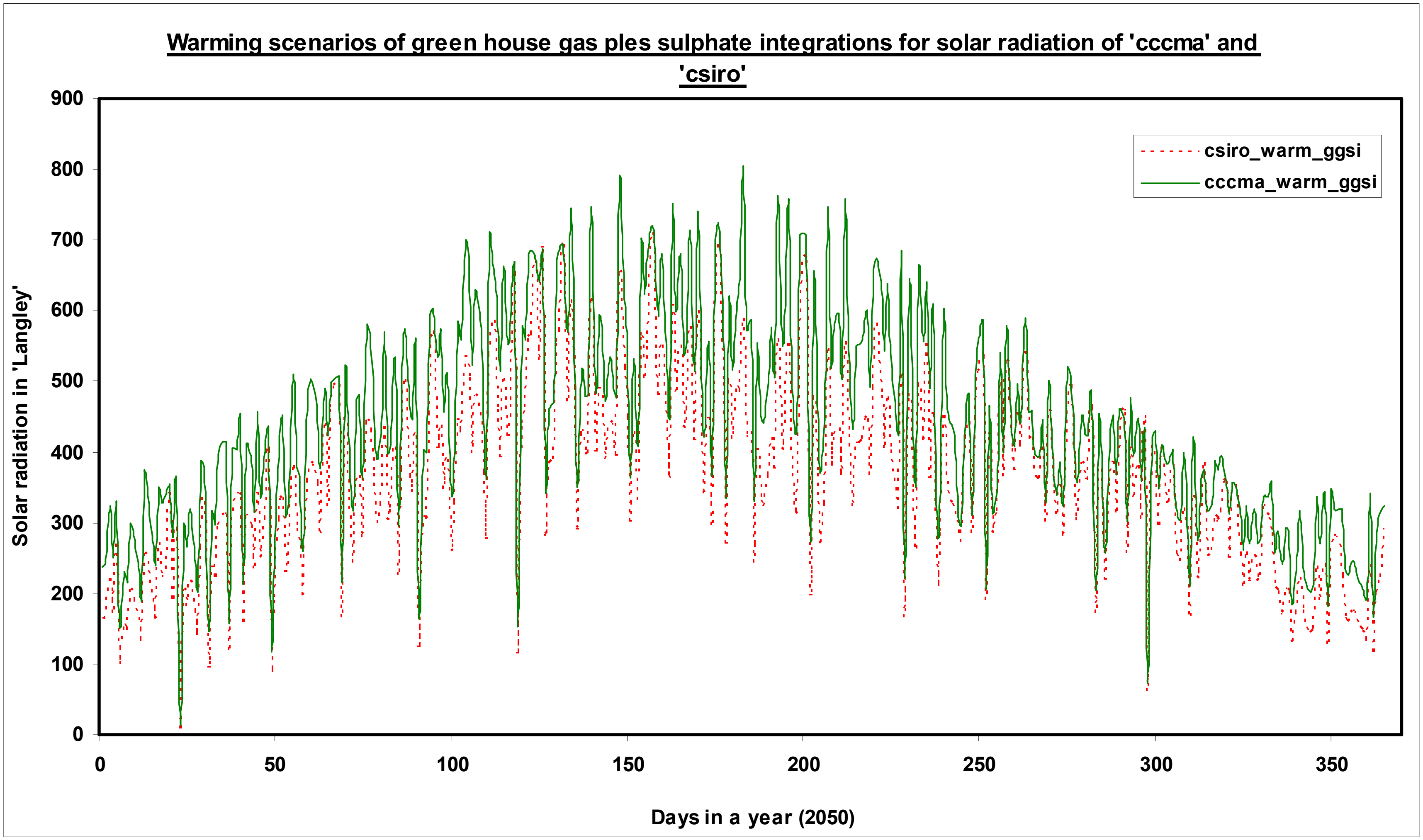

Figure 5.40: Graph showing the warming scenarios of green house gas plus sulphate integration of solar radiation for ‘CCCma’ and ‘CSIRO

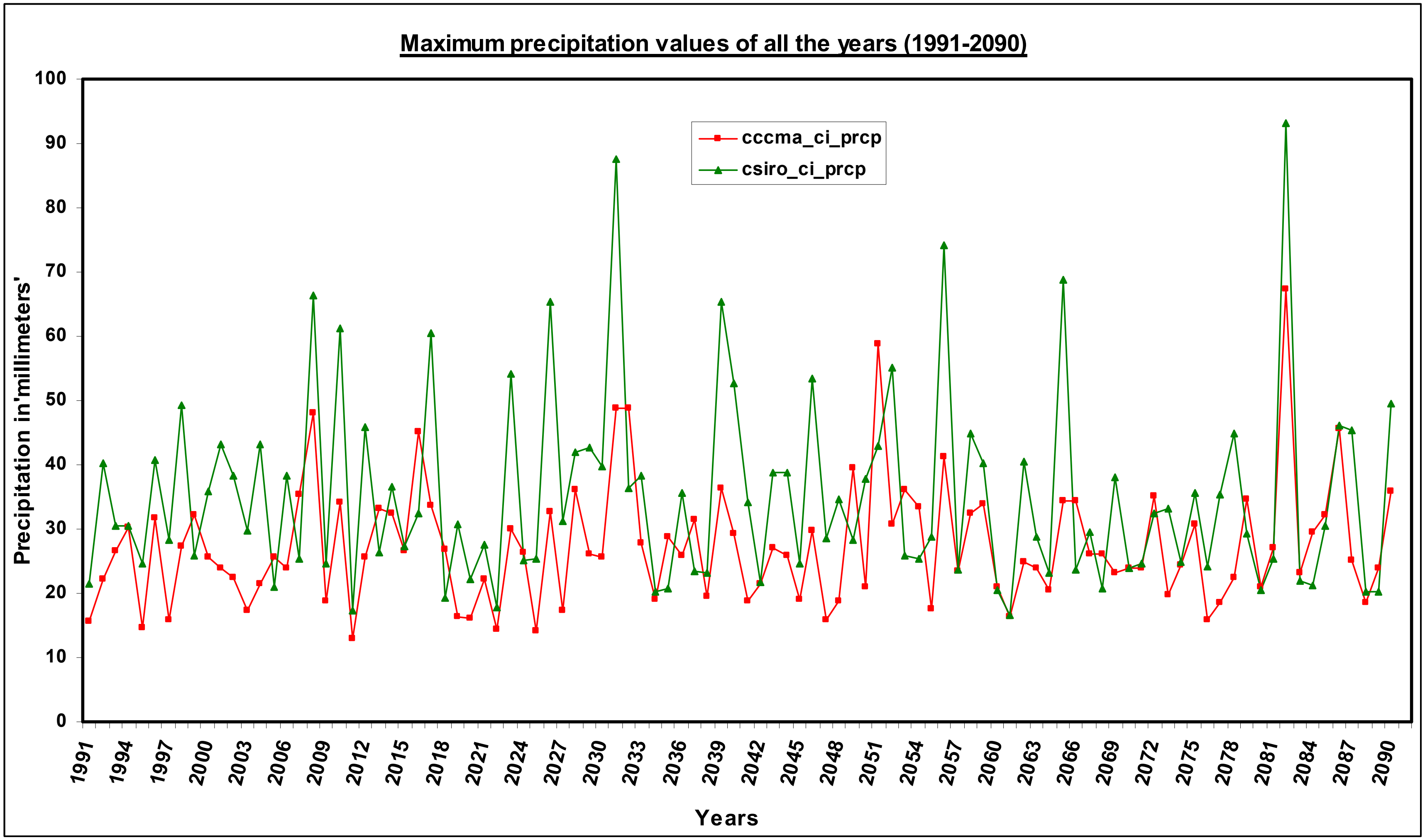

Figure 5.41: Graph showing the maximum values of precipitation of all the years predicted by control integration of CCCma and CSIRO

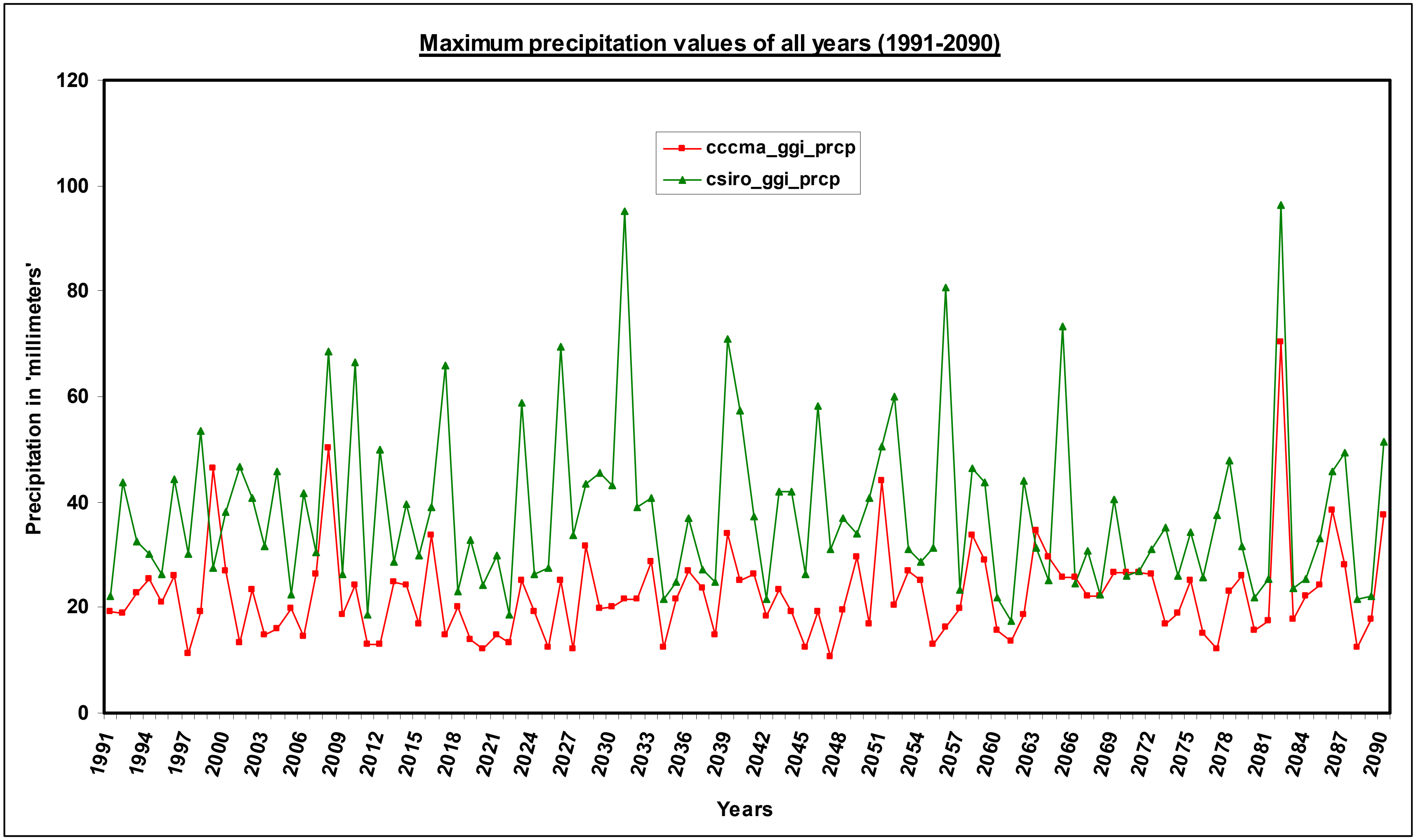

Figure 5.42: Graph showing the maximum values of precipitation of all the years predicted by green house gas integration of CCCma and CSIRO

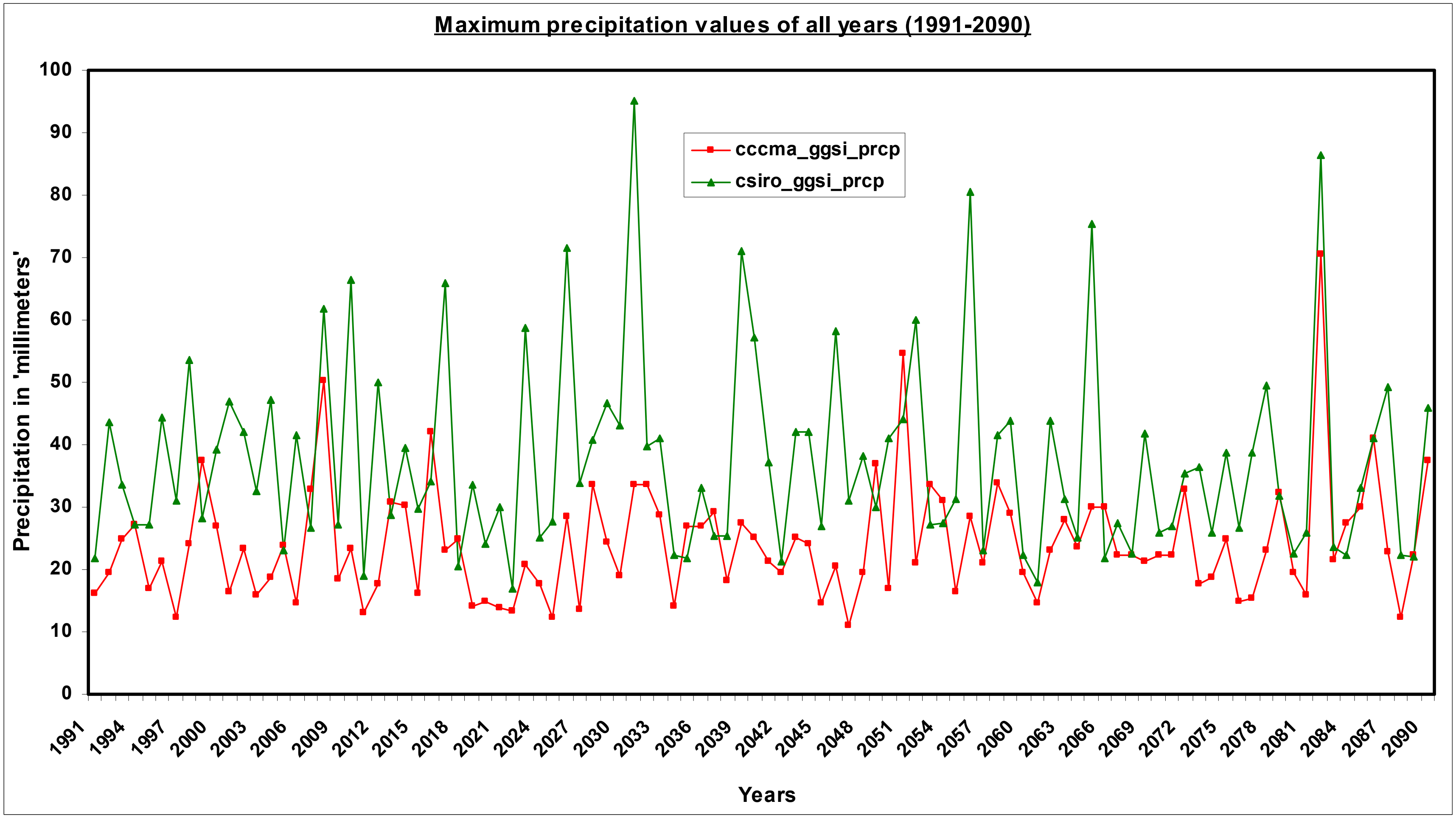

Figure 5.43: Graph showing the maximum values of precipitation of all the years predicted by green house gas plus sulphate integration of CCCma and CSIRO

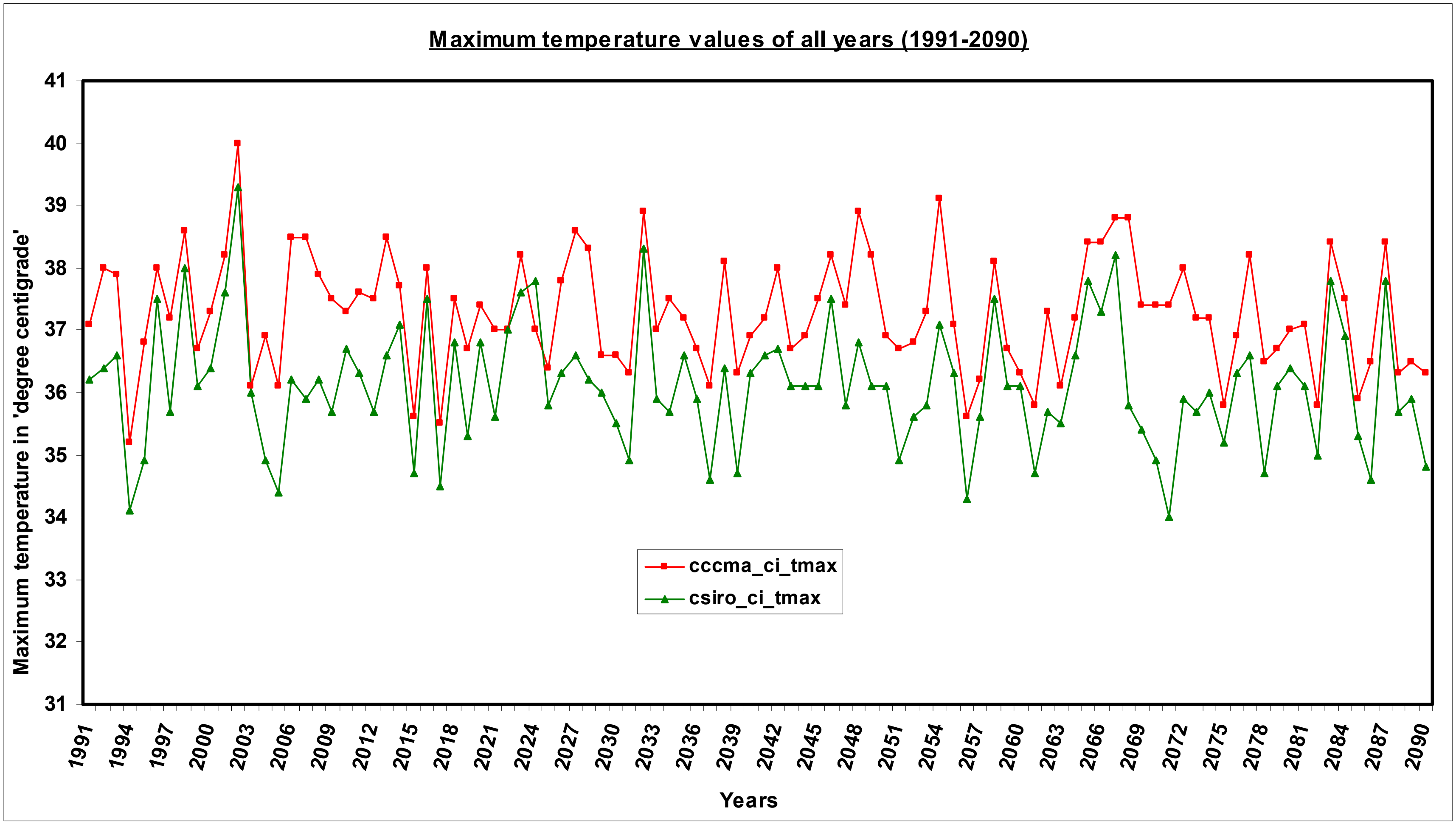

Figure 5.44: Graph showing the maximum values of maximum temperature of all the years predicted by control integration of CCCma and CSIRO

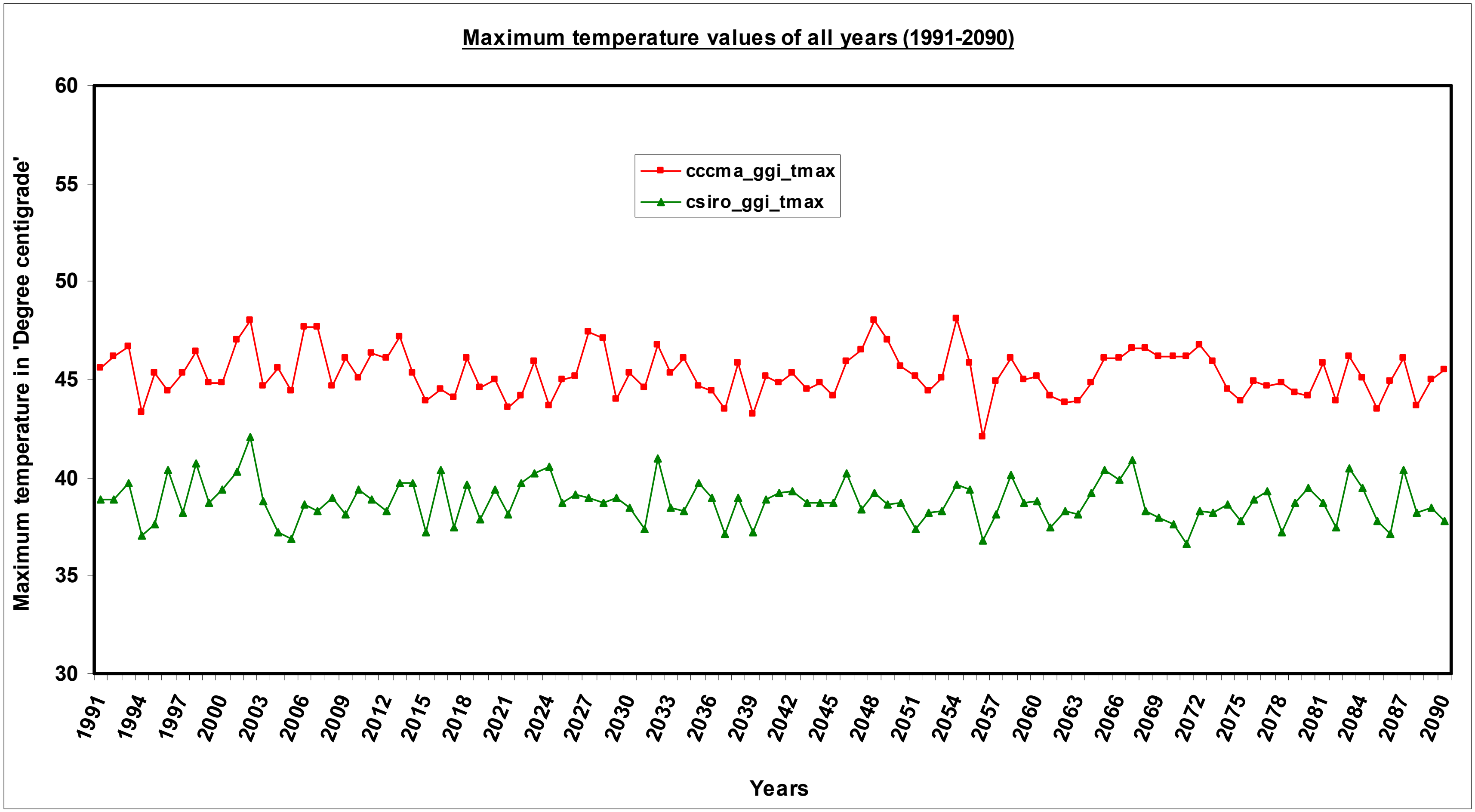

Figure 5.45: Graph showing the maximum values of maximum temperature of all the years predicted by green house gas integration of CCCma and CSIRO

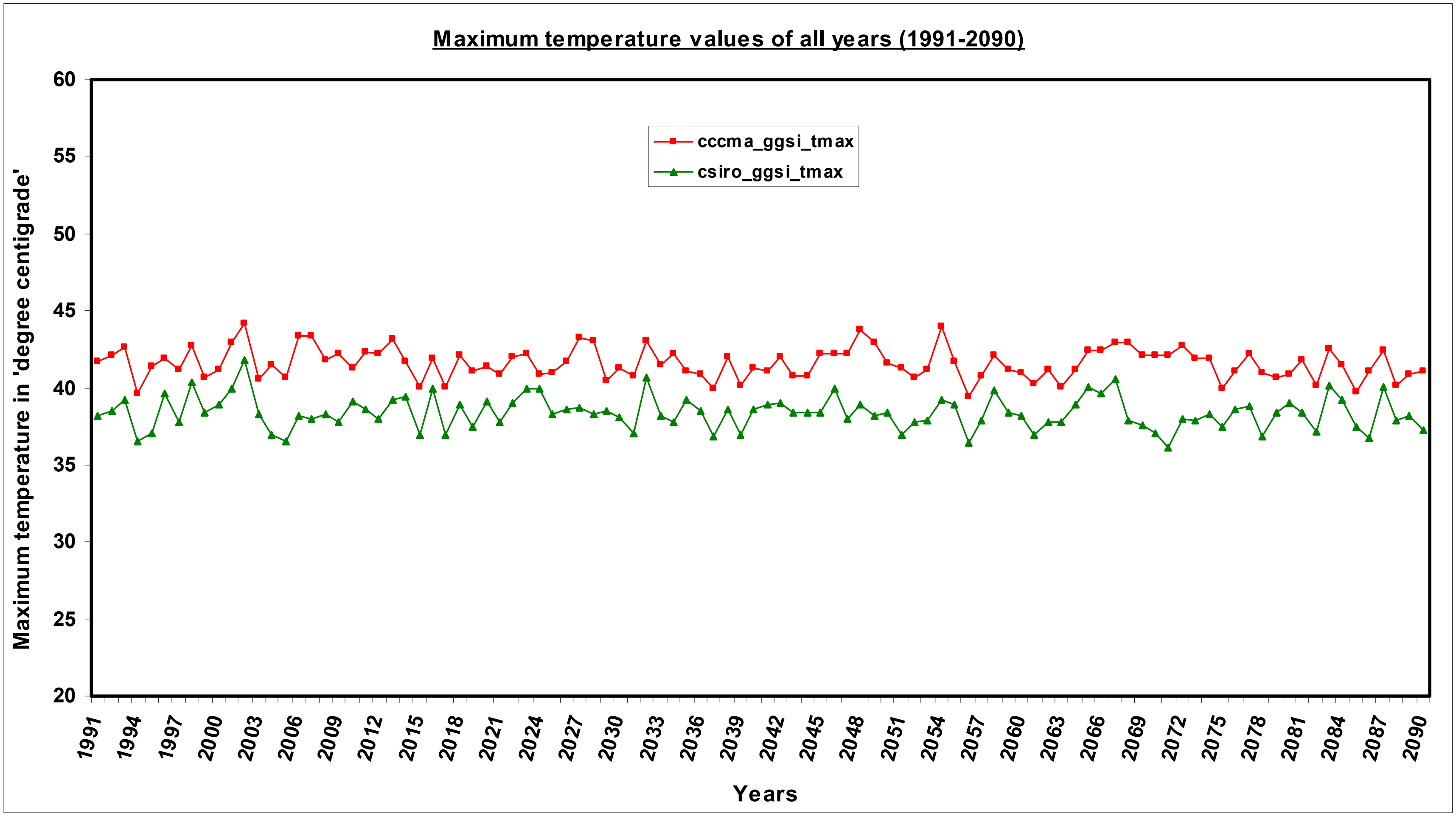

Figure 5.46: Graph showing the maximum values of maximum temperature of all the years predicted by green house gas plus sulphate integration of CCCma and CSIRO

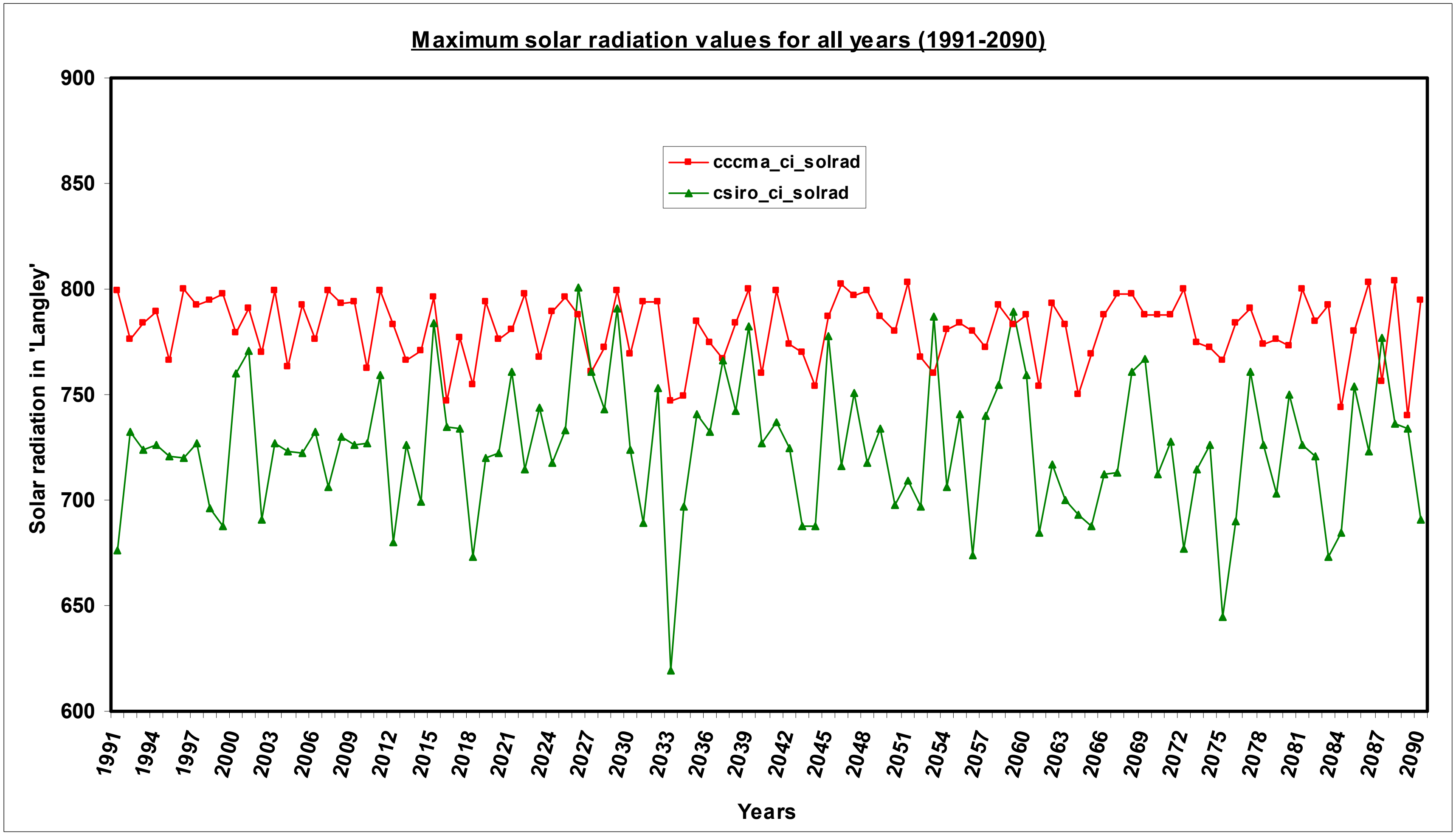

Figure 5.47: Graph showing the maximum values of solar radiation of all the years predicted by control integration of CCCma and CSIRO

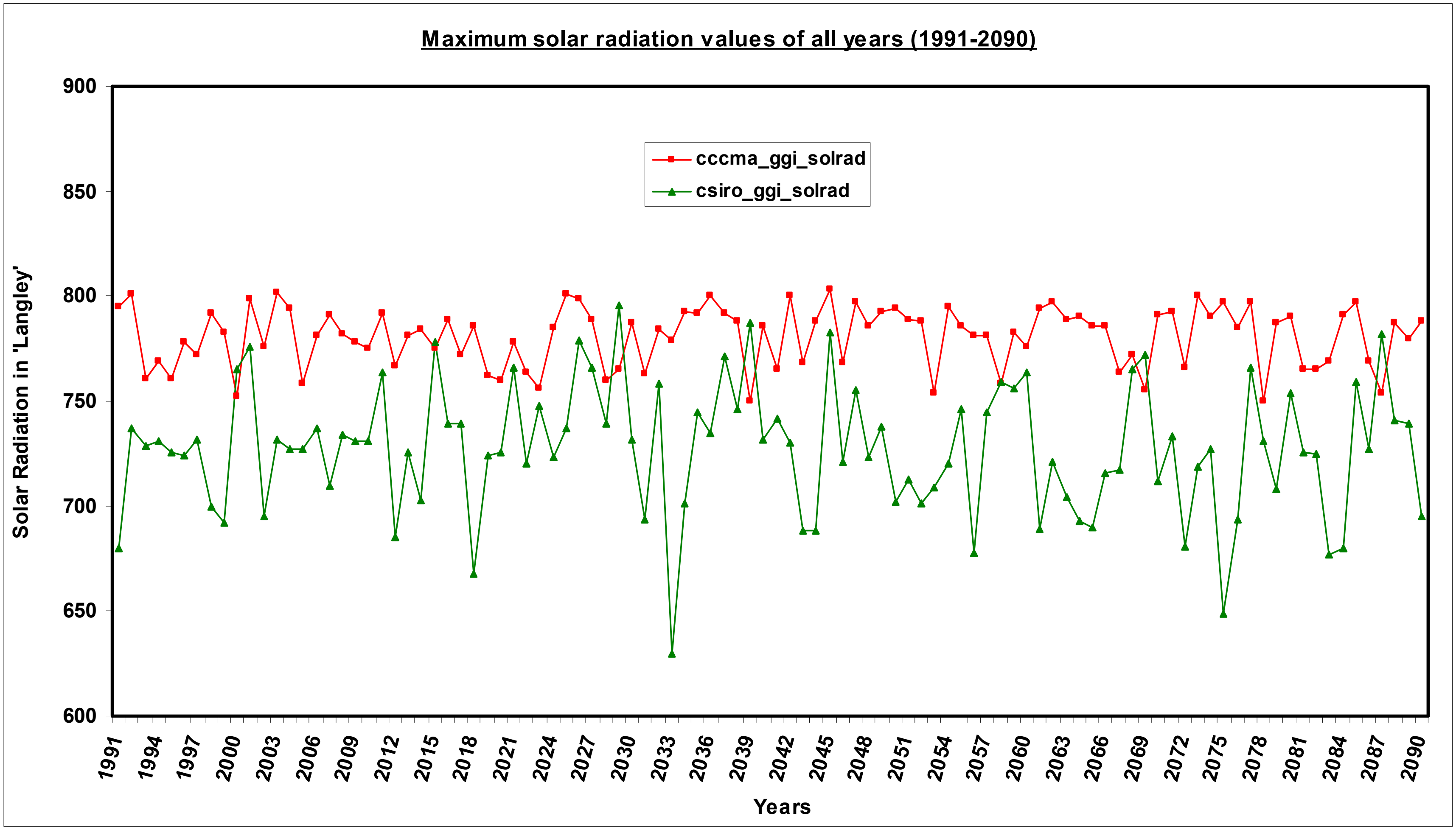

Figure 5.48: Graph showing the maximum values of solar radiation of all the years predicted by green house gas integration of CCCma and CSIRO

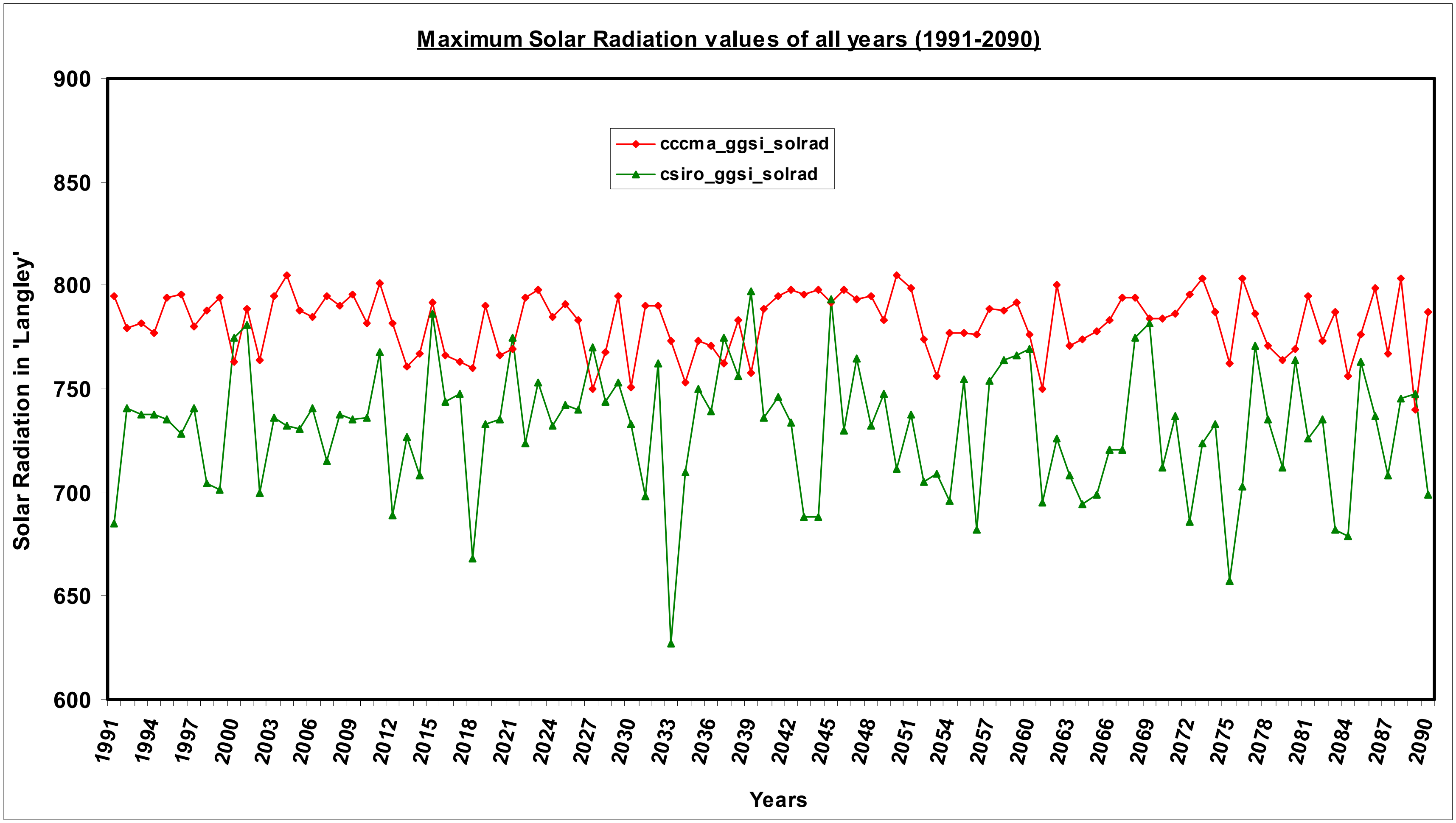

Figure 5.49: Graph showing the maximum values of solar radiation of all the years predicted by green house gas plus sulphateintegration of CCCma and CSIRO

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APPENDIX A
DETAILS OF CLIGEN WEATHER STATION INPUT FILES

Line 1: Station name, state id number, station id number, igcode (2 digit - read but not used in CLIGEN)

Line 2: Latitude, longitude, station years of record,

Line 3: Elevation above sea level (ft), TP5 - maximum 30 minute precipitation depth (inches) (not read by CLIGEN), TP6 - maximum 6-hour precipitation depth (inches).

Line 4: Mean liquid equivalent precipitation depth (inches) for a day precipitation occurs (by month). This value is obtained by taking average of total precipitation for a month and dividing that with the number of days in which precipitation occurred.

Line 5: Standard deviation of daily precipitation value (inches) (by month).

Line 6: Skew coefficient of daily precipitation value (by month).

Line 7: Probability of a wet day following a wet day (by month)

Line 8: Probability of a wet day following a dry day (by month)

Line 9: Mean maximum daily air temperature (degrees Fahrenheit) (by month)

Line 10: Mean minimum daily air temperature (degrees Fahrenheit) (by month)

Line 11: Standard deviation for daily maximum temperatures (degrees Fahrenheit) (by month)

Line 12: Standard deviation for daily minimum temperatures (degrees Fahrenheit)(by month)

Line 13: Mean daily solar radiation (Langley) (by month)

Line 14: Standard deviation for daily solar radiation (Langley) (by month)

Line 15: Mean max. Daily 30 minute liquid precipitation intensity (in/hr) (by month)

Line 16: Mean daily dew point temperature (degrees Fahrenheit) (by month)

Line 17: These 12 values represent a cumulative distribution of compute time to peak rainfall intensity values based upon the National Weather Service 15 minute rainfall data.

Line 18: Percentage of time wind from North (by month)

Line 19: Average N wind velocity (mph) (by month)

Line 20: Standard deviation of N winds (mph) (by month)

Line 21: Skew coefficient of N wind data (by month)

Line 22: Percentage of time wind from NNE (by month)

Line 23: Average NNE wind velocity (mph) (by month)

Line 24: Standard deviation of NNE winds (mph) (by month)

Line 25: Skew coefficient of NNE wind data (by month)

Line 26: Percentage of time wind from NE (by month)

Line 27: Average NE wind velocity (mph) (by month)

Line 28: Standard deviation of NE winds (mph) (by month)

Line 29: Skew coefficient of NE wind data (by month)

Line 30: Percentage of time wind from ENE (by month)

Line 31: Average ENE wind velocity (mph) (by month)

Line 32: Standard deviation of ENE winds (mph) (by month)

Line 33: Skew coefficient of ENE wind data (by month)

Line 34: Percentage of time wind from E (by month)

Line 35: Average E wind velocity (mph) (by month)

Line 36: Standard deviation of E winds (mph) (by month)

Line 37: Skew coefficient of E wind data (by month)

Line 38: Percentage of time wind from ESE (by month)

Line 39: Average ESE wind velocity (mph) (by month)

Line 40: Standard deviation of ESE winds (mph) (by month)

Line 41: Skew coefficient of ESE wind data (by month)

Line 42: Percentage of time wind from SE (by month)

Line 43: Average SE wind velocity (mph) (by month)

Line 44: Standard deviation of SE winds (mph) (by month)

Line 45: Skew coefficient of SE wind data (by month)

Line 46: Percentage of time wind from SSE (by month)

Line 47: Average SSE wind velocity (mph) (by month)

Line 48: Standard deviation of SSE winds (mph) (by month)

Line 49: Skew coefficient of SSE wind data (by month)

Line 50: Percentage of time wind from S (by month)

Line 51: Average S wind velocity (mph) (by month)

Line 52: Standard deviation of S winds (mph) (by month)

Line 53: Skew coefficient of S wind data (by month)

Line 54: Percentage of time wind from SSW (by month)

Line 55: Average SSW wind velocity (mph) (by month)

Line 56: Standard deviation of SSW winds (mph) (by month)

Line 57: Skew coefficient of SSW wind data (by month)

Line 58: Percentage of time wind from SW (by month)

Line 59: Average SW wind velocity (mph) (by month)

Line 60: Standard deviation of SW winds (mph) (by month)

Line 61: Skew coefficient of SW wind data (by month)

Line 62: Percentage of time wind from WSW (by month)

Line 63: Average WSW wind velocity (mph) (by month)

Line 64: Standard deviation of WSW winds (mph) (by month)

Line 65: Skew coefficient of WSW wind data (by month)

Line 66: Percentage of time wind from W (by month)

Line 67: Average W wind velocity (mph) (by month)

Line 68: Standard deviation of W winds (mph) (by month)

Line 69: Skew coefficient of W wind data (by month)

Line 70: Percentage of time wind from WNW (by month)

Line 71: Average WNW wind velocity (mph) (by month)

Line 72: Standard deviation of WNW winds (mph) (by month)

Line 73: Skew coefficient of WNW wind data (by month)

Line 74: Percentage of time wind from NW (by month)

Line 75: Average NW wind velocity (mph) (by month)

Line 76: Standard deviation of NW winds (mph) (by month)

Line 77: Skew coefficient of NW wind data (by month)

Line 78: Percentage of time wind from NNW (by month)

Line 79: Average NNW wind velocity (mph) (by month)

Line 80: Standard deviation of NNW winds (mph) (by month)

Line 81: Skew coefficient of NNW wind data (by month)

Line 82: Percentage of time there are calm conditions (by month).

Line 83: Stations from which wind data was interpolated and weighting factor assigned to each station. (Values are not used internally in CLIGEN).

APPENDIX-B
FORMAT OF CLIGEN WEATHER STATION INPUT FILES

Line 1: format (a41, i2, i4, i2)

Line 2: integer type (integer value from 1-4 to set single storm parameters)

Line 3: format (6x,f7.2, 6x,f7.2, 7x,i3, 7x,i2/12x,i5, 17x,f5.2)

Line 4: format (8x, 12f6.2)

Line 5: format (8x, 12f6.2)

Line 6: format (8x, 12f6.2)

Line 7: format (8x, 12f6.2)

Line 8: format (8x, 12f6.2)

Line 9: format (8x, 12f6.2)

Line 10: format (8x, 12f6.2)

Line 11: format (8x, 12f6.2)

Line 13: format (8x, 12f6.2)

Line 14: format (8x, 12f6.2)

Line 15: format (8x, 12f6.2)

Line 16: format (8x, 12f6.2)

Line 17: format (8x, 12f6.3)

Line 18: format (8x, 12f6.2)

Line 19: format (8x, 12f6.2)

Line 20: format (8x, 12f6.2)

Line 21: format (8x, 12f6.2)

Line 22: format (8x, 12f6.2)

Line 23: format (8x, 12f6.2)

Line 24: format (8x, 12f6.2)

Line 25: format (8x, 12f6.2)

Line 26: format (8x, 12f6.2)

Line 27: format (8x, 12f6.2)

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Line 29: format (8x, 12f6.2)

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Line 53: format (8x, 12f6.2)

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Line 55: format (8x, 12f6.2)

Line 56: format (8x, 12f6.2)

Line 57: format (8x, 12f6.2)

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Line 61: format (8x, 12f6.2)

Line 62: format (8x, 12f6.2)

Line 63: format (8x, 12f6.2)

Line 64: format (8x, 12f6.2)

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Line 70: format (8x, 12f6.2)

Line 71: format (8x, 12f6.2)

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Line 73: format (8x, 12f6.2)

Line 74: format (8x, 12f6.2)

Line 75: format (8x, 12f6.2)

Line 76: format (8x, 12f6.2)

Line 77: format (8x, 12f6.2)

Line 78: format (8x, 12f6.2)

Line 79: format (8x, 12f6.2)

Line 80: format (8x, 12f6.2)

Line 81: format (8x, 12f6.2)

Line 82: format (8x, 12f6.2)

Line 83: format (a19, f6.3, 2(2x, a19, f6.3))

APPENDIX-C
SAMPLE '.ASC'FILE

```
nlon=    7

nlat=    5

xlon

265.5000  266.5000  267.5000  268.5000  269.5000  270.5000  271.5000

 xlat

  27.5000   28.5000   29.5000   30.5000   31.5000

 month=    1

   2.9910    3.0748    3.3492    3.6323    3.9154    4.2571    4.6576

   2.5177    2.6592    2.9817    3.3125    3.6433    4.0214    4.4468

   2.2235    2.3727    2.6966    3.0285    3.3603    3.7328    4.1460

   1.9293    2.0862    2.4115    2.7444    3.0773    3.4442    3.8452

   1.6500    1.8118    2.1337    2.4628    2.7920    3.1502    3.5375

 month=    2

   3.2033    3.3656    3.7836    4.2132    4.6429    5.0851    5.5399

   2.7164    2.9409    3.4059    3.8818    4.3577    4.8335    5.3091

   2.4372    2.6569    3.0940    3.5410    3.9880    4.4401    4.8971

   2.1581    2.3729    2.7822    3.2003    3.6184    4.0467    4.4851

   1.8964    2.1036    2.4814    2.8669    3.2525    3.6535    4.0698

 month=    3

   2.7823    2.8185    3.0199    3.2289    3.4379    3.7050    4.0304

   2.4744    2.5755    2.8262    3.0836    3.3411    3.6360    3.9683

   2.3138    2.4351    2.7110    2.9941    3.2771    3.5665    3.8623

   2.1531    2.2946    2.5959    2.9045    3.2131    3.4970    3.7563

   2.0140    2.1736    2.4939    2.8215    3.1492    3.4246    3.6478

 month=    4

   2.5501    2.5145    2.6040    2.6991    2.7943    3.0078    3.3396
```

2.3421	2.3917	2.5608	2.7353	2.9098	3.1609	3.4884
2.2768	2.3871	2.6454	2.9105	3.1756	3.4735	3.8040
2.2115	2.3825	2.7301	3.0858	3.4414	3.7860	4.1197
2.1713	2.3938	2.8153	3.2458	3.6764	4.0584	4.3920
month=	5					
2.2293	2.2634	2.6213	2.9940	3.3666	3.9246	4.6680
1.9558	2.0787	2.4716	2.8768	3.2819	3.8402	4.5516
1.8908	2.0565	2.4869	2.9293	3.3718	3.9020	4.5201
1.8257	2.0343	2.5022	2.9819	3.4616	3.9638	4.4885
1.8049	2.0464	2.5379	3.0407	3.5436	4.0105	4.4416
month=	6					
1.8991	1.8875	2.5328	3.2080	3.8833	4.4032	4.7679
1.5659	1.6716	2.4024	3.1616	3.9208	4.5019	4.9050
1.3938	1.5449	2.3206	3.1246	3.9287	4.5394	4.9567
1.2217	1.4182	2.2387	3.0877	3.9366	4.5769	5.0083
1.0948	1.3246	2.1642	3.0315	3.8989	4.5514	4.9892
month=	7					
2.6308	3.0120	3.6356	4.2701	4.9046	4.9183	4.3112
2.3917	2.8249	3.5059	4.1982	4.8905	4.9480	4.3709
2.1682	2.5918	3.2562	3.9316	4.6069	4.7082	4.2352
1.9448	2.3588	3.0066	3.6650	4.3234	4.4683	4.0996
1.7278	2.1228	2.7426	3.3725	4.0025	4.1848	3.9196
month=	8					
3.7175	3.9449	4.0238	4.0960	4.1682	3.9025	3.2989
3.1553	3.4351	3.5930	3.7453	3.8977	3.7008	3.1547
2.5537	2.8139	3.0164	3.2163	3.4162	3.3107	2.8999
1.9521	2.1928	2.4399	2.6873	2.9347	2.9207	2.6451
1.3934	1.6117	1.8957	2.1828	2.4698	2.5389	2.3900

month= 9

4.0006	3.8297	4.1799	4.5538	4.9277	5.2739	5.5924
3.6070	3.5793	4.0153	4.4725	4.9296	5.3094	5.6117
3.3673	3.3981	3.8954	4.4139	4.9324	5.3038	5.5281
3.1276	3.2169	3.7754	4.3553	4.9351	5.2982	5.4444
2.9182	3.0585	3.6580	4.2784	4.8987	5.2478	5.3256

month= 10

4.1018	3.7114	3.7743	3.8578	3.9413	4.3253	5.0098
3.3663	3.1332	3.3010	3.4870	3.6730	4.0858	4.7252
2.9774	2.7965	3.0081	3.2376	3.4670	3.8441	4.3687
2.5886	2.4598	2.7153	2.9882	3.2611	3.6024	4.0121
2.2261	2.1437	2.4324	2.7380	3.0436	3.3482	3.6520

month= 11

2.0490	1.9551	2.0936	2.2427	2.3919	2.6403	2.9880
1.4215	1.4193	1.6173	1.8244	2.0315	2.3022	2.6364
1.1920	1.2151	1.4015	1.5953	1.7891	2.0286	2.3136
0.9624	1.0109	1.1857	1.3662	1.5468	1.7550	1.9909
0.7520	0.8229	0.9858	1.1529	1.3200	1.4990	1.6900

month= 12

2.0156	2.1079	2.3423	2.5831	2.8240	3.0703	3.3220
1.4581	1.6056	1.9007	2.2025	2.5043	2.7928	3.0682
1.1905	1.3232	1.6054	1.8944	2.1834	2.4658	2.7415
0.9229	1.0407	1.3101	1.5863	1.8626	2.1388	2.4149
0.6854	0.7884	1.0406	1.2996	1.5587	1.8243	2.0966

APPENDIX-D
FORTRAN CODE TO MODIFY CLIGEN PARAMETER FILE

```
Program main
 implicit none
interface
subroutine read_GCMs_data(fname,var_array,lon,lat,nlon,nlat)
implicit none
character(len=132)::fname
real,pointer,dimension(:,:,:):: var_array
real,pointer,dimension(:):: lon,lat
integer::i,j,kk,nlon,nlat,nmonths
end subroutine read_GCMs_data
real function k2f(temp)
real ,intent(in):: temp
end function k2f
end interface
!

 integer :: count,nearestlongitude,nearestlatitude,kk
 integer:: nmonths,nlon,nlat,iunit,ounit,i,j,ilon,ilat
 real,pointer,dimension(:)::lon,lat

real,pointer,dimension(:,:,:)::GCMs_pcp,GCMs_tmax,GCMs_tmin,GCMs_srd,GCMs_sp
hum,GCMs_temp
 real::mon(12),m(12)

!!!! CLIGEN PARAMETER FILE !!!!!!!
type CLIGEN_var
character(len=8):: varname
real,dimension(12):: data
end type CLIGEN_var
type (CLIGEN_var):: mean_p,s_dev_p,skew_p,p_w_w,p_w_d,tmax_ave,tmin_ave, &
  sd_tmax,sd_tmin,sol_rad,sd_sol,mx_5p,dew_pt,time_pk,per_n,per_n_mean, &
  per_n_std,per_n_skew,per_nne,per_nne_mean,per_nne_std,per_nne_skew, &
  per_ne,per_ne_mean,per_ne_std,per_ne_skew,per_ene,per_ene_mean,per_ene_std, &
  per_ene_skew,per_e,per_e_mean,per_e_std,per_e_skew,per_ese,per_ese_mean, &
  per_ese_std,per_ese_skew,per_se,per_se_mean,per_se_std,per_se_skew,per_sse, &
  per_sse_mean,per_sse_std,per_sse_skew,per_s,per_s_mean,per_s_std,per_s_skew, &
  per_ssw,per_ssw_mean,per_ssw_std,per_ssw_skew,per_sw,per_sw_mean,per_sw_std,
&

per_sw_skew,per_wsw,per_wsw_mean,per_wsw_std,per_wsw_skew,per_w,per_w_mean
,per_w_std, &
```

```
per_w_skew,per_wnw,per_wnw_mean,per_wnw_std,per_wnw_skew,per_nw,per_nw_m
ean, &
  per_nw_std,per_nw_skew,per_nnw,per_nnw_mean,per_nnw_std,per_nnw_skew,calm

integer:: station_id_number,state_id_number,igcode
character(len=41):: station_name
character(len=6):: latt_name,lon_name,years_name
character(len=12)::elevation_name
character(len=5)::type_name,tp5_name
character(len=4)::tp6_name
character(len=80)::junk
real:: sta_lon,sta_lat,elevation,tp5,tp6
integer:: sta_nyears,sta_type
character                                                    (len=132)::
ppath,fname,scen_name,CLIGEN_par_inp,CLIGEN_par_out,fname1
real :: iilon,iilat,ratio

nmonths=12
 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!   OPEN   (UNIT=11,   FILE='cccma_pcp_1900_2099.asc',   FORM='FORMATTED',
STATUS='OLD')
!  OPEN   (UNIT=12,   FILE='cccma_tmax_1900_2099.asc',   FORM='FORMATTED',
STATUS='OLD')
!  OPEN   (UNIT=13,   FILE='cccma_tmin_1900_2099.asc',   FORM='FORMATTED',
STATUS='OLD')
!   OPEN   (UNIT=14,   FILE='cccma_srd_1900_2099.asc',   FORM='FORMATTED',
STATUS='OLD')

fname='cccma_ggsi.prcp_1961-1990.asc'
call read_GCMs_data(fname,GCMs_pcp,lon,lat,nlon,nlat)
    do kk=1,nmonths
  write(*,*) 'precip'
    do j=1,nlat
    write(*,*)(GCMs_pcp(i,j,kk),i=1,nlon)
    enddo
    enddo
fname='cccma_ggsi.temp_1961-1990.asc'
call read_GCMs_data(fname,GCMs_temp,lon,lat,nlon,nlat)
fname='cccma_ggsi.tmax_1961-1990.asc'
call read_GCMs_data(fname,GCMs_tmax,lon,lat,nlon,nlat)
fname='cccma_ggsi.tmin_1961-1990.asc'
call read_GCMs_data(fname,GCMs_tmin,lon,lat,nlon,nlat)
fname='cccma_ggsi.sphum_1961-1990.asc'
call read_GCMs_data(fname,GCMs_sphum,lon,lat,nlon,nlat)
fname='cccma_ggsi.solrad_1961-1990.asc'
```

```
call read_GCMs_data(fname,GCMs_srd,lon,lat,nlon,nlat)

! Read the CLIGEN Parameter File and generate parameter files
do ilat=1,nlat
do ilon=1,nlon
!! Get the CLIGEN input file and output file names

iunit=90
ounit=91

ppath='../../ipcc/CLIGEN/base/'
scen_name='CLIGEN_base_'
call gen_fname(ppath,scen_name,360.0-lon(ilon),lat(ilat),CLIGEN_par_inp)
open(unit=iunit,file=CLIGEN_par_inp,status='unknown')

ppath='../../ipcc/CLIGEN/cccma/cccma_base/cccma_base_ggsi/'
!ppath='../../ipcc/CLIGEN/cccma/cccma_warm/cccma_warm_ggsi/'


scen_name='CLIGEN_cccma_ggsi_base'
call gen_fname(ppath,scen_name,360.0-lon(ilon),lat(ilat),CLIGEN_par_out)

open(unit=ounit,file=CLIGEN_par_out,status='unknown')
print *, 'CLIGEN input file = ', CLIGEN_par_inp
print *, 'CLIGEN output file = ', CLIGEN_par_out
!!!!!! Read CLIGEN Parameter File Begin !!!!!!!
!! line 1
read(iunit,'(a41,i2,i4,i2)') station_name,state_id_number,station_id_number,igcode
write(ounit,'(a41,i2,i4,i2)') station_name,state_id_number,station_id_number,igcode
!! line 2
read(iunit,'(a6,f7.2,a6,f7.2,1x,a6,f5.1,a5,I2)')
latt_name,sta_lat,lon_name,sta_lon,years_name,sta_nyears,type_name,sta_type
write(ounit,'(a6,f7.2,a6,f7.2,1x,a6,f5.1,a5,I2)')
latt_name,sta_lat,lon_name,sta_lon,years_name,sta_nyears,type_name,sta_type
!! line 3
read(iunit,'(a12,f7.1,a5,f5.2,1x,a4,f5.2)')
elevation_name,elevation,tp5_name,tp5,tp6_name,tp6
write(ounit,'(a12,f7.1,a5,f5.2,1x,a4,f5.2)')
elevation_name,elevation,tp5_name,tp5,tp6_name,tp6
!! line 4
read(iunit,'(a8,12f6.2)') mean_p%varname,(mean_p%data(i),i=1,12)
do i=1,nmonths
GCMs_pcp(ilon,ilat,i)=GCMs_pcp(ilon,ilat,i)/25.4 ! convert precip from mm to inches
enddo
write(ounit,'(a8,12f6.2)') mean_p%varname,(GCMs_pcp(ilon,ilat,i),i=1,12)
!! line 5
```

```
read(iunit,'(a8,12f6.2)') s_dev_p%varname,(s_dev_p%data(i),i=1,12)
do i=1,nmonths
ratio = GCMs_pcp(ilon,ilat,i)/mean_p%data(i)
s_dev_p%data(i)= ratio*s_dev_p%data(i)
enddo
write(ounit,'(a8,12f6.2)') s_dev_p%varname,(s_dev_p%data(i),i=1,12)
!! line 6
read(iunit,'(a8,12f6.2)') skew_p%varname,(skew_p%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') skew_p%varname,(skew_p%data(i),i=1,12)
!! line 7
read(iunit,'(a8,12f6.2)') p_w_w%varname,(p_w_w%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') p_w_w%varname,(p_w_w%data(i),i=1,12)
!! line 8
read(iunit,'(a8,12f6.2)') p_w_d%varname,(p_w_d%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') p_w_d%varname,(p_w_d%data(i),i=1,12)
!! line 9
read(iunit,'(a8,12f6.2)') tmax_ave%varname,(tmax_ave%data(i),i=1,12)
do i=1,nmonths
GCMs_tmax(ilon,ilat,i)=k2f(GCMs_tmax(ilon,ilat,i) )! convert temp to Fahrenheit
enddo
write(ounit,'(a8,12f6.2)') tmax_ave%varname,(GCMs_tmax(ilon,ilat,i),i=1,12)
!! line 10
read(iunit,'(a8,12f6.2)') tmin_ave%varname,(tmin_ave%data(i),i=1,12)
do i=1,nmonths
GCMs_tmin(ilon,ilat,i)=k2f(GCMs_tmin(ilon,ilat,i) )! convert temp to Fahrenheit
enddo
write(ounit,'(a8,12f6.2)') tmin_ave%varname,(GCMs_tmin(ilon,ilat,i),i=1,12)
!! line 11
read(iunit,'(a8,12f6.2)') sd_tmax%varname,(sd_tmax%data(i),i=1,12)
do i=1,nmonths
ratio = GCMs_tmax(ilon,ilat,i)/tmax_ave%data(i)
sd_tmax%data(i)= ratio*sd_tmax%data(i)
enddo
write(ounit,'(a8,12f6.2)') sd_tmax%varname,(sd_tmax%data(i),i=1,12)
!! line 12
read(iunit,'(a8,12f6.2)') sd_tmin%varname,(sd_tmin%data(i),i=1,12)
do i=1,nmonths
ratio = GCMs_tmin(ilon,ilat,i)/tmin_ave%data(i)
sd_tmin%data(i)= ratio*sd_tmin%data(i)
enddo
write(ounit,'(a8,12f6.2)') sd_tmin%varname,(sd_tmin%data(i),i=1,12)
!! line 13
read(iunit,'(a8,12f6.0)') sol_rad%varname,(sol_rad%data(i),i=1,12)
do i=1,nmonths
GCMs_srd(ilon,ilat,i)=GCMs_srd(ilon,ilat,i)*2.064 ! convert to langleys
enddo
```

```
write(ounit,'(a8,12f6.0)') sol_rad%varname,(GCMs_srd(ilon,ilat,i),i=1,12)
!! line 14
read(iunit,'(a8,12f6.1)') sd_sol%varname,(sd_sol%data(i),i=1,12)
do i=1,nmonths
ratio = GCMs_srd(ilon,ilat,i)/sol_rad%data(i)
sd_sol%data(i)= ratio*sd_sol%data(i)
enddo
write(ounit,'(a8,12f6.1)') sd_sol%varname,(sd_sol%data(i),i=1,12)
!! line 15
read(iunit,'(a8,12f6.2)') mx_5p%varname,(mx_5p%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') mx_5p%varname,(mx_5p%data(i),i=1,12)
!! line 16
read(iunit,'(a8,12f6.2)') dew_pt%varname,(dew_pt%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') dew_pt%varname,(dew_pt%data(i),i=1,12)
!! line 17
read(iunit,'(a8,12f6.3)') time_pk%varname,(time_pk%data(i),i=1,12)
write(ounit,'(a8,12f6.3)') time_pk%varname,(time_pk%data(i),i=1,12)
!! line 18
read(iunit,'(a8,12f6.2)') per_n%varname,(per_n%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_n%varname,(per_n%data(i),i=1,12)
!! line 19
read(iunit,'(a8,12f6.2)') per_n_mean%varname,(per_n_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_n_mean%varname,(per_n_mean%data(i),i=1,12)
!! line 20
read(iunit,'(a8,12f6.2)') per_n_std%varname,(per_n_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_n_std%varname,(per_n_std%data(i),i=1,12)
!! line 21
read(iunit,'(a8,12f6.2)') per_n_skew%varname,(per_n_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_n_skew%varname,(per_n_skew%data(i),i=1,12)
!! line 22
read(iunit,'(a8,12f6.2)') per_nne%varname,(per_nne%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nne%varname,(per_nne%data(i),i=1,12)
!! line 23
read(iunit,'(a8,12f6.2)') per_nne_mean%varname,(per_nne_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nne_mean%varname,(per_nne_mean%data(i),i=1,12)
!! line 24
read(iunit,'(a8,12f6.2)') per_nne_std%varname,(per_nne_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nne_std%varname,(per_nne_std%data(i),i=1,12)
!! line 25
read(iunit,'(a8,12f6.2)') per_nne_skew%varname,(per_nne_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nne_skew%varname,(per_nne_skew%data(i),i=1,12)
!! line 26
read(iunit,'(a8,12f6.2)') per_ne%varname,(per_ne%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ne%varname,(per_ne%data(i),i=1,12)
!! line 27
read(iunit,'(a8,12f6.2)') per_ne_mean%varname,(per_ne_mean%data(i),i=1,12)
```

```
write(ounit,'(a8,12f6.2)') per_ne_mean%varname,(per_ne_mean%data(i),i=1,12)
!! line 28
read(iunit,'(a8,12f6.2)') per_ne_std%varname,(per_ne_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ne_std%varname,(per_ne_std%data(i),i=1,12)
!! line 29
read(iunit,'(a8,12f6.2)') per_ne_skew%varname,(per_ne_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ne_skew%varname,(per_ne_skew%data(i),i=1,12)
!! line 30
read(iunit,'(a8,12f6.2)') per_ene%varname,(per_ene%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ene%varname,(per_ene%data(i),i=1,12)
!! line 31
read(iunit,'(a8,12f6.2)') per_ene_mean%varname,(per_ene_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ene_mean%varname,(per_ene_mean%data(i),i=1,12)
!! line 32
read(iunit,'(a8,12f6.2)') per_ene_std%varname,(per_ene_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ene_std%varname,(per_ene_std%data(i),i=1,12)
!! line 33
read(iunit,'(a8,12f6.2)') per_ene_skew%varname,(per_ene_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ene_skew%varname,(per_ene_skew%data(i),i=1,12)
!! line 34
read(iunit,'(a8,12f6.2)') per_e%varname,(per_e%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_e%varname,(per_e%data(i),i=1,12)
!! line 35
read(iunit,'(a8,12f6.2)') per_e_mean%varname,(per_e_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_e_mean%varname,(per_e_mean%data(i),i=1,12)
!! line 36
read(iunit,'(a8,12f6.2)') per_e_std%varname,(per_e_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_e_std%varname,(per_e_std%data(i),i=1,12)
!! line 37
read(iunit,'(a8,12f6.2)') per_e_skew%varname,(per_e_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_e_skew%varname,(per_e_skew%data(i),i=1,12)
!! line 38
read(iunit,'(a8,12f6.2)') per_ese%varname,(per_ese%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ese%varname,(per_ese%data(i),i=1,12)
!! line 39
read(iunit,'(a8,12f6.2)') per_ese_mean%varname,(per_ese_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ese_mean%varname,(per_ese_mean%data(i),i=1,12)
!! line 40
read(iunit,'(a8,12f6.2)') per_ese_std%varname,(per_ese_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ese_std%varname,(per_ese_std%data(i),i=1,12)
!! line 41
read(iunit,'(a8,12f6.2)') per_ese_skew%varname,(per_ese_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ese_skew%varname,(per_ese_skew%data(i),i=1,12)
!! line 42
read(iunit,'(a8,12f6.2)') per_se%varname,(per_se%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_se%varname,(per_se%data(i),i=1,12)
```

```
!! line 43
read(iunit,'(a8,12f6.2)')per_se_mean%varname,(per_se_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_se_mean%varname,(per_se_mean%data(i),i=1,12)
!! line 44
read(iunit,'(a8,12f6.2)') per_se_std%varname,(per_se_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_se_std%varname,(per_se_std%data(i),i=1,12)
!! line 45
read(iunit,'(a8,12f6.2)') per_se_skew%varname,(per_se_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_se_skew%varname,(per_se_skew%data(i),i=1,12)
!! line 46
read(iunit,'(a8,12f6.2)') per_sse%varname,(per_sse%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sse%varname,(per_sse%data(i),i=1,12)
!! line 47
read(iunit,'(a8,12f6.2)') per_sse_mean%varname,(per_sse_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sse_mean%varname,(per_sse_mean%data(i),i=1,12)
!! line 48
read(iunit,'(a8,12f6.2)') per_sse_std%varname,(per_sse_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sse_std%varname,(per_sse_std%data(i),i=1,12)
!! line 49
read(iunit,'(a8,12f6.2)') per_sse_skew%varname,(per_sse_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sse_skew%varname,(per_sse_skew%data(i),i=1,12)
!! line 50
read(iunit,'(a8,12f6.2)') per_s%varname,(per_s%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_s%varname,(per_s%data(i),i=1,12)
!! line 51
read(iunit,'(a8,12f6.2)') per_s_mean%varname,(per_s_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_s_mean%varname,(per_s_mean%data(i),i=1,12)
!! line 52
read(iunit,'(a8,12f6.2)') per_s_std%varname,(per_s_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_s_std%varname,(per_s_std%data(i),i=1,12)
!! line 53
read(iunit,'(a8,12f6.2)') per_s_skew%varname,(per_s_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_s_skew%varname,(per_s_skew%data(i),i=1,12)
!! line 54
read(iunit,'(a8,12f6.2)') per_ssw%varname,(per_ssw%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ssw%varname,(per_ssw%data(i),i=1,12)
!! line 55
read(iunit,'(a8,12f6.2)') per_ssw_mean%varname,(per_ssw_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ssw_mean%varname,(per_ssw_mean%data(i),i=1,12)
!! line 56
read(iunit,'(a8,12f6.2)') per_ssw_std%varname,(per_ssw_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ssw_std%varname,(per_ssw_std%data(i),i=1,12)
!! line 57
read(iunit,'(a8,12f6.2)') per_ssw_skew%varname,(per_ssw_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_ssw_skew%varname,(per_ssw_skew%data(i),i=1,12)
!! line 58
```

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read(iunit,'(a8,12f6.2)') per_sw%varname,(per_sw%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sw%varname,(per_sw%data(i),i=1,12)
!! line 59
read(iunit,'(a8,12f6.2)') per_sw_mean%varname,(per_sw_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sw_mean%varname,(per_sw_mean%data(i),i=1,12)
!! line 60
read(iunit,'(a8,12f6.2)') per_sw_std%varname,(per_sw_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sw_std%varname,(per_sw_std%data(i),i=1,12)
!! line 61
read(iunit,'(a8,12f6.2)') per_sw_skew%varname,(per_sw_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_sw_skew%varname,(per_sw_skew%data(i),i=1,12)
!! line 62
read(iunit,'(a8,12f6.2)') per_wsw%varname,(per_wsw%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_wsw%varname,(per_wsw%data(i),i=1,12)
!! line 63
read(iunit,'(a8,12f6.2)') per_wsw_mean%varname,(per_wsw_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_wsw_mean%varname,(per_wsw_mean%data(i),i=1,12)
!! line 64
read(iunit,'(a8,12f6.2)') per_wsw_std%varname,(per_wsw_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_wsw_std%varname,(per_wsw_std%data(i),i=1,12)
!! line 65
read(iunit,'(a8,12f6.2)') per_wsw_skew%varname,(per_wsw_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_wsw_skew%varname,(per_wsw_skew%data(i),i=1,12)
!! line 66
read(iunit,'(a8,12f6.2)') per_w%varname,(per_w%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_w%varname,(per_w%data(i),i=1,12)
!! line 67
read(iunit,'(a8,12f6.2)') per_w_mean%varname,(per_w_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_w_mean%varname,(per_w_mean%data(i),i=1,12)
!! line 68
read(iunit,'(a8,12f6.2)') per_w_std%varname,(per_w_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_w_std%varname,(per_w_std%data(i),i=1,12)
!! line 69
read(iunit,'(a8,12f6.2)') per_w_skew%varname,(per_w_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_w_skew%varname,(per_w_skew%data(i),i=1,12)
!! line 70
read(iunit,'(a8,12f6.2)') per_wnw%varname,(per_wnw%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_wnw%varname,(per_wnw%data(i),i=1,12)
!! line 71
read(iunit,'(a8,12f6.2)') per_wnw_mean%varname,(per_wnw_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_wnw_mean%varname,(per_wnw_mean%data(i),i=1,12)
!! line 72
read(iunit,'(a8,12f6.2)') per_wnw_std%varname,(per_wnw_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_wnw_std%varname,(per_wnw_std%data(i),i=1,12)
!! line 73
read(iunit,'(a8,12f6.2)') per_wnw_skew%varname,(per_wnw_skew%data(i),i=1,12)
```

```
write(ounit,'(a8,12f6.2)') per_wnw_skew%varname,(per_wnw_skew%data(i),i=1,12)
!! line 74
read(iunit,'(a8,12f6.2)') per_nw%varname,(per_nw%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nw%varname,(per_nw%data(i),i=1,12)
!! line 75
read(iunit,'(a8,12f6.2)') per_nw_mean%varname,(per_nw_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nw_mean%varname,(per_nw_mean%data(i),i=1,12)
!! line 76
read(iunit,'(a8,12f6.2)') per_nw_std%varname,(per_nw_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nw_std%varname,(per_nw_std%data(i),i=1,12)
!! line 77
read(iunit,'(a8,12f6.2)') per_nw_skew%varname,(per_nw_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nw_skew%varname,(per_nw_skew%data(i),i=1,12)
!! line 78
read(iunit,'(a8,12f6.2)') per_nnw%varname,(per_nnw%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nnw%varname,(per_nnw%data(i),i=1,12)
!! line 79
read(iunit,'(a8,12f6.2)') per_nnw_mean%varname,(per_nnw_mean%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nnw_mean%varname,(per_nnw_mean%data(i),i=1,12)
!! line 80
read(iunit,'(a8,12f6.2)') per_nnw_std%varname,(per_nnw_std%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nnw_std%varname,(per_nnw_std%data(i),i=1,12)
!! line 81
read(iunit,'(a8,12f6.2)') per_nnw_skew%varname,(per_nnw_skew%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') per_nnw_skew%varname,(per_nnw_skew%data(i),i=1,12)
!! line 82
read(iunit,'(a8,12f6.2)') calm%varname,(calm%data(i),i=1,12)
write(ounit,'(a8,12f6.2)') calm%varname,(calm%data(i),i=1,12)

do i=1,11

read(iunit,'(a80)') junk
write(ounit,'(a80)') junk

enddo

enddo
enddo

end program main

subroutine read_GCMs_data(fname,var_array,lon,lat,nlon,nlat)
implicit none
character(len=*)::fname
real,pointer,dimension(:,:,:):: var_array
real,pointer,dimension(:):: lon,lat
```

```
integer::i,j,kk,nlon,nlat,nmonths
nmonths=12
 OPEN (UNIT=11, FILE=fname, FORM='FORMATTED', STATUS='OLD')
    read(11,'(8x,I5)') nlon
    read(11,'(8x,I5)') nlat
!     write(*,*) "nlon,nlat",nlon,nlat
    allocate(lon(nlon))
    allocate(lat(nlat))
                        read(11,*)
                        read(11,*)(lon(i),i=1,nlon)
!                         write(*,*)(lon(i),i=1,nlon)
                        read(11,*)
    read(11,*)(lat(i),i=1,nlat)
!   write(*,*)(lat(i),i=1,nlat)
!   write(*,*) "lon,lat allocated"
    allocate(var_array(nlon,nlat,nmonths))
!   write(*,*) "var_array allocated"
    do kk=1,nmonths
                        read(11,*)
    do j=1,nlat
    read(11,*)(var_array(i,j,kk),i=1,nlon)
    enddo
    enddo
    do kk=1,nmonths
!   write(*,*)
    do j=1,nlat
!     write(*,*)(var_array(i,j,kk),i=1,nlon)
    enddo
    enddo
close (11)
end subroutine read_GCMs_data

real function k2f(temp)
real ,intent(in):: temp
k2f=((temp-273.15)*1.8)+32.0
end function k2f

subroutine gen_fname(ppath,scen_name,iilon,iilat,fname)
character (len=*):: ppath,fname,scen_name
character (len=132):: int_file
character (len=6) :: iclon,iclat
real :: iilon,iilat
write(int_file,FMT='(f6.1)')iilon
read(int_file,FMT='(a6)')iclon
print *, iclon
write(int_file,FMT='(f6.1)')iilat
```

```
read(int_file,FMT='(a6)')iclat
fname=trim(trim(adjustl(ppath))//trim(adjustl(scen_name))//trim(adjustl(iclon))//"_"//trim
(adjustl(iclat))//".par")
end subroutine
```

APPENDIX-E
FORTRAN CODE FOR CALCULATING THE DISTANCES BETWEEN THE GRIDS

```
program DISTANCE_GRID

implicit none
integer,dimension(:,:),allocatable:: station_id
real,dimension(:,:,:),allocatable:: distance
real,dimension(:),allocatable:: prcp_desi
real,dimension(:,:,:),allocatable:: weight
integer,dimension(:),allocatable:: no_point
real,dimension(:),allocatable:: denom
!integer,dimension(1:10,1:20):: station_id
real,dimension(:,:),allocatable:: lat,long,prcp
integer :: max_grids,allocation_status,grid,i,j,k,l,lines,h
real::pi,temp
!,m1,m2,m3,m4,m5,m6,m7,m8,m9,m10,m11,m12
character(len = 100)::name

pi=3.14159265358979323846

!print*,"type the no. of max grids"
!read*,max_grids
max_grids = 35

allocate(station_id(1:max_grids,1:1000),stat = allocation_status)
allocate(distance(1:max_grids,1:1000,1:1000),stat = allocation_status)
allocate(weight(1:max_grids,1:1000,1:1000),stat = allocation_status)
allocate(no_point(1:max_grids),stat = allocation_status)
allocate(denom(1:max_grids),stat = allocation_status)
allocate(prcp_desi(1:1000),stat = allocation_status)
allocate(lat(1:max_grids,1:1000),stat = allocation_status)
allocate(long(1:max_grids,1:1000),stat = allocation_status)
allocate(prcp(1:1000,1:1000),stat = allocation_status)
if(allocation_status>0)then
print*,"error"
end if

open(unit=90,file='formatted_distances_negative.txt',status='unknown')
open(unit=100,file='formatted_distances_out.txt',status='unknown')
open(unit=110,file='formatted_5_out.txt',status='unknown')
!open(unit=9,file="27.5_94.5.par",status='unknown')
read(90,*)
do grid = 1, max_grids
```

```
do i = 1,100
read(90,fmt = 50)station_id(grid,i),lat(grid,i),long(grid,i)
50 format(i6,1x,f5.2,1x,f5.2)
print*,station_id(grid,i),lat(grid,i),long(grid,i)
if( station_id(grid,i) == 111111)then
exit
end if
no_point(grid) = no_point(grid) +1
end do
print*,"No. of point in the above grid",no_point(grid)
end do

do grid= 1, max_grids
!write(unit=100,*)'grid'
do i=1,1
!write(unit=100,*)no_point
do j=1,no_point(grid)
if(i/=j) then

temp=pi/180.0

 distance(grid,i,j) =69.1*(180.0/pi)*(acos(sin(lat(grid,i)*temp)*sin(lat(grid,j)*temp) &
  &                          +cos(lat(grid,i)*temp)*cos(lat(grid,j)*temp)*cos(long(grid,j)*temp-
long(grid,i)*temp)))
!print*,distance(grid,i,j)
print*,grid,i,j,distance(grid,i,j)

!write(unit=100,fmt=60)grid,i,j,distance(grid,i,j)
!60 format (i2,2x,i2,2x,i2,2x,f10.3)

end if
end do
end do
end do

do grid = 1,max_grids
do i = 1,1
do j = 1,no_point(grid)-1
if( i /= j)then
do k = j,no_point(grid)-1
if(distance(grid,i,j) >= distance(grid,i,(k+1) ) ) then
temp = distance(grid,i,j)
distance(grid,i,j) = distance(grid,i,(k+1))
distance(grid,i,k+1) = temp
temp = station_id(grid,j)
station_id(grid,j) = station_id(grid,(k+1))
```

```
station_id(grid,k+1) = temp
temp = lat(grid,j)
lat(grid,j) = lat(grid,(k+1))
lat(grid,k+1) = temp
temp = long(grid,j)
long(grid,j) = long(grid,(k+1))
long(grid,k+1) = temp
end if
end do

write(unit=100,fmt=60)grid,i,j,distance(grid,i,j),station_id(grid,j),lat(grid,j),long(grid,j)
60 format (i2,2x,i2,2x,i2,2x,f10.3,1x,i6,1x,f6.2,1x,f6.2)
end if
end do
end do
end do
do grid = 1,max_grids
do i =1,1
do j = 1,6

write(unit=110,fmt=70)grid,i,j,distance(grid,i,j),station_id(grid,j),lat(grid,j),long(grid,j)
70 format (i2,2x,i2,2x,i2,2x,f10.3,1x,i6,1x,f6.2,1x,f6.2)
end do
end do
end do

end program distance_grid
```

VITA

Suchita Potta was born on September 13, 1976, in Cumbum, India to Mrs Suseela Devi and Mr Solomon Potta. She graduated from Sri Venkateswara University, Tirupathi, with a Bachelor of Science degree in Civil Engineering in the year 1999. She was married to Sarath Annareddy on August 21, 1999. She came to the United States to join the graduate school at Louisiana State University Agricultural and Mechanical College in the Department of Civil Engineering. She defended her Masters Thesis on 29th of July 2004 and is currently a candidate for the degree of Master of Science in Civil Engineering for fall 2004.